Volume 5, Number 4
ISSN: 0869-5938

July–August 1997

STRATIGRAPHY AND GEOLOGICAL CORRELATION

Official English Translation of *Stratigrafiya. Geologicheskaya Korrelyatsiya*

Editor-in-Chief
Boris S. Sokolov

Member of the Russian Academy of Sciences
Counsellor of the Presidium of the Russian Academy of Sciences

Journal of the Fundamental and Applied Aspects of Stratigraphy and the Correlation of Geologic Events and Processes in Time and Space

МАИК НАУКА/INTERPERIODICA PUBLISHING

Stratigraphy and Geological Correlation

(Stratigrafiya. Geologicheskaya Korrelyatsiya)

ISSN: 0869-5938

Editor-in-Chief
Boris S. Sokolov
Member of the Russian Academy of Sciences,
Counsellor of the Presidium of the Russian Academy of Sciences

Address for correspondence: Staromonetnyi per. 22, Moscow, 109180 Russia
Phones: 7-(095) 231-2164; Fax: 7-(095) 233-5590.

Deputy Editor-in-Chief
Mikhail A. Semikhatov
Member of the Russian Academy of Sciences
Head of Laboratory, Geological Institute,
Russian Academy of Sciences

Assistant Editor
Aleksei B. Herman
Senior Scientist,
Geological Institute,
Russian Academy of Sciences

EDITORIAL BOARD

Mikhail A. Akhmet'ev
Dr. Sci. (Geol.-Min.),
Head of Laboratory, Geological Institute,
Russian Academy of Sciences

Aleksandr S. Alekseev
Professor, Department of Paleontology,
Moscow State University

Mikhail N. Alekseev
Dr. Sci. (Geol.-Min.),
Chief Scientist, Geological Institute,
Russian Academy of Sciences

Ivan A. Basov
Dr. Sci. (Geol.-Min.),
Deputy Director, Institute of the Lithosphere,
Russian Academy of Sciences

Michael G. Basset
Professor, National Museum of Wales,
Cardiff, UK

William A. Berggren
Professor, Department of Geology and
Geophysics, Woods Hole Oceanographic
Institute, USA

Elena V. Bibikova
Dr. Sci. (Geol.-Min.), Chief Scientist,
Vernadskii Institute of Geochemistry
and Analytical Chemistry,
Russian Academy of Sciences

Nikita A. Bogdanov
Corresponding Member of the Russian Academy
of Sciences, Director, Institute of the
Lithosphere, Russian Academy of Sciences

Kiyotaka Chinzei
Professor, Institute of Geology,
University of Tokyo, Tokyo, Japan

Nikolai M. Chumakov
Dr. Sci. (Geol.-Min.),
Chief Scientist, Geological Institute,
Russian Academy of Sciences

Yurii B. Gladenkov
Dr. Sci. (Geol.-Min.),
Head of Laboratory, Geological Institute,
Russian Academy of Sciences

Dmitrii L. Kaljo
Professor, Institute of Geology, Tallinn, Estonia

Victor E. Khain
Member of the Russian Academy of Sciences,
Chief Scientist, Institute of the Lithosphere,
Russian Academy of Sciences

Lidiya A. Nevesskaya
Dr. Sci. (Biol.), Laboratory Chief, Institute of
Paleontology, Russian Academy of Sciences

Aleksandr G. Ponomarenko
Dr. Sci. (Biol.), Chief Scientist, Institute of
Paleontology, Russian Academy of Sciences

Jurgen Remane
Professor, Institute de Géologie,
Université de Neuchâtel, Switzerland

Aleksei Yu. Rozanov
Dr. Sci. (Geol.-Min.),
Director, Institute of Paleontology,
Russian Academy of Sciences

Boris A. Sokolov
Dr. Sci. (Geol.-Min.),
Professor, Dean, Faculty of Geology,
Moscow State University

Otto Walliser
Professor,
Göttingen University, Göttingen, Germany

Sun Weigo
Professor, Nanjing Institute of Geology
and Paleontology, Academia Sinica, China

Victor A. Zakharov
Dr. Sci. (Geol.-Min.),
Head of Laboratory, Institute of Geology,
Geophysics, and Mineralogy,
Siberian Branch, Russian Academy
of Sciences, Novosibirsk

Aleksandr I. Zhamoida
Corresponding Member of the Russian Academy
of Sciences, Russian Geological Institute,
St. Petersburg

Staff Editor Tamara V. Trishkina

Editor of the English Translation Anatolii Ya. Sharas'kin, Dr. Sci. (Geol.-Min.)

SCOPE

Stratigraphy and Geological Correlation (Stratigrafiya. Geologicheskaya Korrelyatsiya) is the only journal in the world designed to provide comprehensive coverage of the fundamental and applied aspects of stratigraphy and the correlation of geological events and processes in time and space. Articles are based on the results of multidisciplinary research, and are directed toward researchers, university professors, students, and geologists interested in understanding stratigraphy and the chronological features of the world's geological record.

Stratigraphy and Geological Correlation is abstracted and/or indexed in *Petroleum Abstracts*, Research Alert, SciSearch, *Current Contents* (Physical, Chemical, and Earth Sciences) and *World Translations Index*.

SUBSCRIPTION OFFICE
INTERPERIODICA
P.O. BOX 1831, BIRMINGHAM, AL 35201-1831 USA
PHONE: (800) 633-4931; (205) 995-1567 (outside US and Canada); FAX: (205) 995-1588

PUBLISHER
МАИК НАУКА/INTERPERIODICA PUBLISHING
PROFSOYUZNAYA UL. 90, MOSCOW, 117864 RUSSIA
PHONE: 7-(095) 336-1600; FAX: 7-(095) 336-0666
E-mail: compmg@maik.rssi.ru
Web Site: http://www.maik.rssi.ru

SUBSCRIPTION PRICES (1997, Volume 5, 6 issues)
US $769.00 (North America), $884.00 (other). A 5% discount is given on 2-year orders. Subscriptions may be entered at any time. Orders may be placed at agencies or directly. 5% discount to all subscription agencies. Cancellations not allowed except for duplicate payment. Prepayment required. Advance payment required in US$/US bank. MasterCard/Visa accepted. Checks payable to *Stratigraphy and Geological Correlation* or Interperiodica.

Stratigraphy and Geological Correlation (ISSN: 0869-5938) is published bimonthly for (US dollars) $769.00 (North America), outside North America $884.00 per year by MAIK Nauka/Interperiodica Publishing, 5724 Hwy. 280 East, Birmingham, Alabama 35242-5724 USA. Periodical Postage Paid at Birmingham, Alabama, and additional Mailing Offices. POSTMASTER: Send address changes to *Stratigraphy and Geological Correlation*, P.O. Box 1831, Birmingham, Alabama 35201 USA.

The journal was founded in 1993.

Original Russian Edition Copyright © 1997 by the Russian Academy of Sciences
and the Division of Geology, Geophysics, Geochemistry, and Mining Sciences.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

Contents

Vol. 5, No. 4, 1997

Simultaneous English language translation of the journal is available from МАИК Наука/Interperiodica Publishing (Russia). *Stratigraphy and Geological Correlation* ISSN 0869-5938.

The Permian (Tatarian) Flora from the Kotel'nich Vertebrate Locality (Kirov Oblast)
A. V. Goman'kov 309

Palynoassemblages from Deposits of the Crater Lakes of the Tunguska Paleovolcanic Area
V. A. Naumov and I. V. Luzina 319

The Paramonovo Formation of the Albian in the European Part of Russia and Its Age as Indicated by Microfauna
L. I. Kasintsova and A. G. Olfer'ev 334

Correlation of the Eocene Marine Sediments from Northwestern Eurasia (West Siberia and the Volga Region) Based on Microphytofossils
Z. I. Glezer, L. A. Panova, I. P. Tabachnikova, and S. G. Vyalova 342

The Lower Miocene of the Tara–Irtysh Region: Stratigraphy, Paleobotany, Paleomagnetism
V. A. Martynov, Z. N. Gnibidenko, and V. P. Nikitin 353

The El-Ghab Rift Depression in Syria: Its Structure, Stratigraphy, and History of Development
E. V. Devyatkin, A. E. Dodonov, E. V. Sharkov, V. S. Zykin, A. N. Simakova, K. Khatib, and H. Nseir 362

The Middle Pleistocene Stratigraphy of Belarus
F. Yu. Velichkevich, G. K. Khursevich, T. B. Rylova, and G. I. Litvinyuk 375

Correlation of Tectono-Stratigraphic Complexes of the Southeastern Sikhote Alin
V. A. Mikhailov 391

Brief Communications

First Finds of Silurian–Lower Devonian Conodonts in Southern Mongolia and Their Biostratigraphic Implications
A. M. Vorozhbitov 401

New Age Data for the Upper Cenozoic Suifun Formation in the Stratotype Region (Southern Primor'e)
B. I. Pavlyutkin 408

Personalia

The Contribution of N. A. Golovkinskii to Theoretical Stratigraphy (1834–1897)
S. I. Romanovskii 413

Stratigraphy and Geological Correlation, Vol. 5, No. 4, 1997, pp. 309–318. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 4, 1997, pp. 3–12.
Original Russian Text Copyright © 1997 by Goman'kov.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

The Permian (Tatarian) Flora from the Kotel'nich Vertebrate Locality (Kirov Oblast)

A. V. Goman'kov

Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia

Received June 13, 1995

Abstract—Plant remains (macrofossils and miospores) from the exposure near the town of Kotel'nich, Kirov oblast, which is primarily known as a vertebrate locality, are considered. The macrofossil assemblage can be referred to the *Tatarina* flora, but it contains unusually abundant arthrophytes. Miospores indicate an older age of the locality than previously accepted. This is supported by the position of the locality in the stratotype section of the Tatarian Stage at the Vyatka River (the Yurpalovo Beds of Forsh). The significance of the studied flora for the correlation of the stratotype section with other sections in the Russian platform and, above all, with the reference section at the Sukhona River is discussed. Taphonomic analysis of the late Tatarian flora localities suggests that this locality was formed in the extensive lake basin not far from a shore.

Key words: *plant fossils, Kotel'nich, macrofossils, miospores, stratigraphy, the Tatarian Stage, taphonomy*

INTRODUCTION

An exposure located at the right bank of the Vyatka River near the town of Kotel'nich, Kirov oblast, has long attracted the attention of geologists (Tikhvinskaya, 1946; V'yushkov, 1953; Efremov and V'yushkov, 1955, with a comprehensive bibliography; Ignat'ev, 1962; Gubin, 1989; Tverdokhlebov and Shminke, 1990; Ivakhnenko, 1994; Ochev, 1995; Tatarinov, 1995) owing to its huge size, unusual for the Russian platform (a scarp, about 30 m high, stretches almost continuously along the Vyatka River bank for more than 30 km), and as one of the richest localities of late Tatarian vertebrates. According to the recently proposed typification of the Tatarian Stage (Goman'kov, 1992b), this exposure is in the stratotype region, and the fossils found here can complete the paleontological description (which is not comprehensive) of the stratotype of the Tatarian Stage.

The fossil plants from the Kotel'nich Locality were first reported by V'yushkov (1953), but until recently, they have not been systematically collected and studied. Neither the exact position of the flora-bearing deposits in the locality, nor the burial conditions and taxonomic composition of the floral assemblage have been defined.

The plant remains from the Kotel'nich Locality were specially collected for the first time by myself in 1986. In addition to plant macrofossils, the flora-bearing lens yielded spores and pollen, which were also studied. In 1992, the locality was additionally studied by I.D. Sukacheva and A.E. Golland. I sincerely thank them for permission to study their collection. The support of the geological cooperative society *Kamennyi Tsvetok* and E.S. Bushmanova (Kirov Museum of Earth Natural History *Petros*) allowed me to visit this locality again, to collect additional macrofossils, and to define the stratigraphic position of the flora-bearing lens. I am very grateful to these colleagues for their help. The results of the analysis of these collections (nearly 180 rock samples with plant imprints and a palynospectrum consisting of 186 specimens) formed the basis of this article.

STRATIGRAPHIC SECTION AND FLORAL ASSEMBLAGES OF THE LOCALITY

As a result of field examinations in 1986 and 1993, the Kotel'nich section was subdivided into the following lithologically uniform successive members (from the base upward, Fig. 1a).

1. Red mudstone with rare bluish gray sandy spots and abundant white calcareous concretions, which locally form some laterally inpersistent interbeds. This member contains the greatest amount of fossil vertebrate bones. Its visible thickness is up to 7 m.

2. Fine-grained, loose, massive to fine-bedded quartz sandstone of brownish orange color. Northward, the bed is facially replaced by grayish green coarse-grained polymictic sandstone, or by mudstone analogous to the overlying member.

In the central part of the exposure (at the Vanyushonki Village), the thickness of the member approaches 15 m,

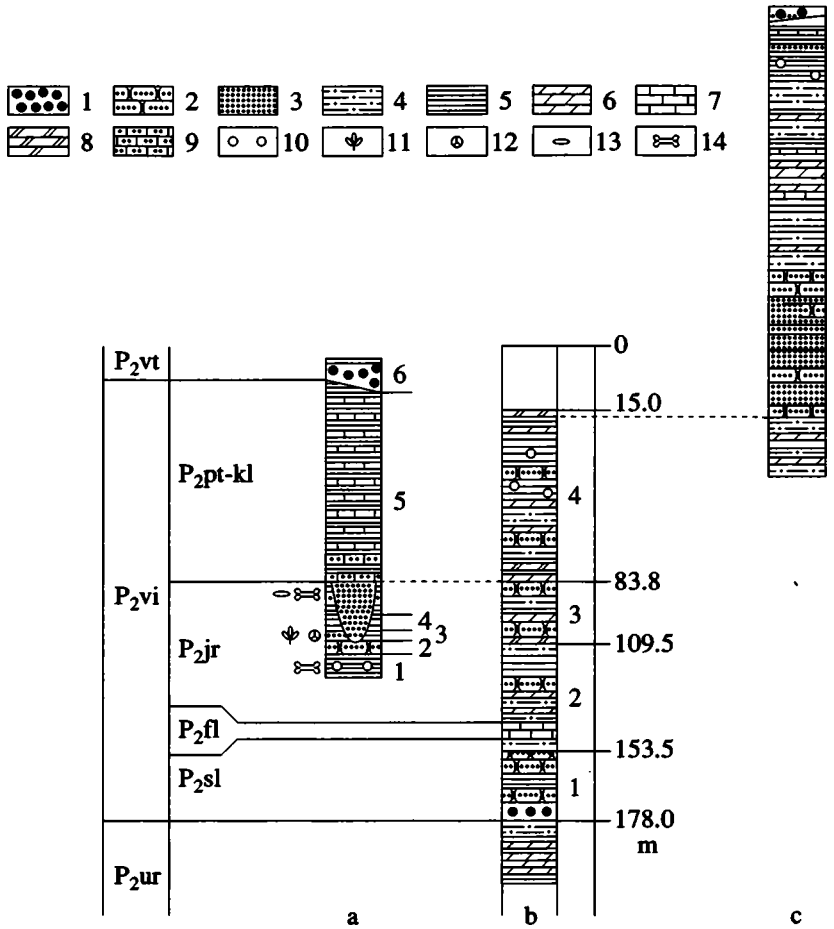


Fig. 1. Different schemes of correlation between sequences exposed at the town of Kotel'nich and recovered by the reference Kotel'nich borehole: (a) Section of the Kotel'nich exposure with indicated member numbers according to the author (for explanations, see the text); (b) Upper part of the reference Kotel'nich borehole, according to Ignat'ev; (c) Section of the Kotel'nich exposure according to Ignat'ev. On the left, the Vyatka River section, according to the scheme of Forsh (1963): P_2ur, Urzhum Horizon, P_2vi, Vishkil' Horizon, P_2vt, Vyatka Horizon, P_2sl, Slobodskoi Beds; P_2fl, Filiny Beds; P_2jr, Yurpalovo Beds; P_2pt-kl, Putyatino and Kalininskaya Beds.

(1) conglomerates; (2) sandstones; (3) sands; (4) siltstones; (5) mudstones; (6) marls; (7) limestones; (8) sandy marls; (9) sandy limestones; (10) calcareous concretions; (11) plant macrofossils, (12) spores and pollen, (13) ostracods, (14) vertebrates.

but it gradually decreases down to 1–2 m from north to south.

3. Red massive mudstone with irregular abundant spots of bluish and greenish gray fine-grained polymictic sandstone. The thickness is 4–6 m.

4. Grayish brown massive fine-splintered mudstone with abundant parting fissures filled with bright red clays, owing to which the member looks generally pink. The thickness is 8.5 m. It is reduced to 3 m at the southern margin of the exposure (at the Nagovitsyny Village).

5. Mudstone analogous to that of Member 1. The calcareous concretions usually form inpersistent irregular beds of light gray lumpy limestones, which vary in thickness from 10 cm to 1 m and are responsible for the striped aspect of the member. The interbeds in the lower part of the member are sandy or represent horizons of bluish gray fine-grained sandstones. This part of the member, about 20 m thick, also includes lenses of grayish and yellowish green (tobacco-like) coarse-grained polymictic sandstones, locally with conglomerates at the base. The maximal thickness of these lenses is 15 m. Therefore, they are locally embedded into the underlying members down to the uppermost beds of Member 2. Both the sandy lenses and the basal red mudstones contain some fossil vertebrate bones. A single sandy lens yielded an ostracod asssemblage (Tverdokhlebov and Shminke,1990). The thickness of the member is about 90 m.

6. A conglomerate composed of poorly rounded pebbles (diameter 0.5–5 cm) of red mudstones and white limestones, which are cemented with gray

coarse-grained polymictic sandstone. The visible thickness is up to 10 m.

The flora-bearing deposits of the Kotel'nich Locality represent a small (approximately 10 m in lateral extension and 1 m in thickness) lens inside Member 3 near the Chizhi Farmstead. The lens is composed of dark gray massive siltstone substituted laterally by coarse-grained sandstones. In addition to fossil plants, it contains ostracod shells, fish scales, and rare imprints of tetrapod bones.

The vegetal macrofossils are mostly represented by frequently limonitized imprints lacking phytoleims. The latter mostly occur as formless coalified fragments of arthrophytes without cuticules resistant to maceration. Only four specimens provided suitable cuticles.

The macrofossil assemblage contains the following taxa identified by myself: *Algites* sp. AVG-1, *Phyllotheca* aff. *turnaensis* Gorelova, *Paracalamites* sp., *Pecopteris* sp. AVG-1, *Peltaspermopsis* (?) sp., *Alicospermum* sp., *Tatarina cospicua* S. Meyen, *Phylladoderma* (*Aequistomia*) sp. indet., *Permotheca sardykense* Zalessky, *Pursongia beloussovae* (Radczenko) Gomankov et S. Meyen, and *Geinitzia* sp. (Plate I).

The palynospectrum derived from the same flora-bearing deposits (Plate II) is dominated by the ribbed quasisaccate pollen of genus *Protohaploxypinus* (*P. dvinensis* (Sedova) Hart (32.8%; other species, 12.9%) and pollen of *Vitreisporites pallidus* (Reissinger) Nilsson (17.2%). The content of the monosaccate pollen similar to that of genus *Cladaitina* is rather high (8.1%). The ribbed asaccate pollen (genera *Vittatina* and *Weylandites*) and *Vesicaspora* ex gr. *magnalis* (Andreeva) Hart are present in small amounts (about 4%). *Vesicaspora arifera* (Andreeva) Hart, the quasimonosaccate pollen of *Cordaitina* type, and spores of *Neoraistrickia* type occur as single grains (0.5–2% each).

THE NOMENCLATURE OF THE SUBDIVISIONS OF THE TATARIAN STAGE

Before discussing the age of the assemblages under consideration, some remarks should be made on the nomenclature. The Tatarian Stage is traditionally divided into the Urzhum, Severnaya Dvina, and Vyatka horizons (here listed from the base upward). The name "Severnaya Dvina" has been long known to be unacceptable for nomenclature reasons. Olfer'ev (1974) and later myself (Goman'kov, 1992b) proposed the name "Kotel'nich Horizon" for the corresponding interval of the section. However, this name has already been applied by Tikhvinskaya (1946) to another unit. Therefore I suggest the name "Vishkil' for the middle horizon of the Tatarian Stage (derived from the Vishkil' Village located at the southern margin of the Kotel'nich exposure in the Kotel'nich district, Kirov oblast).

The Vishkil' Horizon, whose stratotype stretches along the Vyatka River from the mouth of the Bredekha River to the Povoiska Village in the Arbazh district, Kirov oblast, is supposed to correspond to the Slobodskoi, Filiny, Yurpalovo, Putyatino, and Kalininskaya beds in the scheme of Forsh (1963). I suggest choosing the boundary between the white massive limestone bed that crowns the section of the Urzhum Formation and the monotonous red clayey-sandy member of the upper Tatarian, which is exposed at the right bank of the Vyatka River near the Povoiska Village, as a stratotype of the lower boundary of this horizon. The stratotype of its upper boundary can be chosen between the member of brown-red mudstones with abundant calcareous concretions of the Kalininskaya Beds and the medium-grained polymictic cross-bedded grayish green sandstones of the Bykovskaya Beds of Forsh. This boundary can be observed at the right bank of the Vyatka River near the former Putyatino Village in the Nagorsk district, the Kirov oblast. Such an interpretation of the Vishkil' Horizon supposes that stratotypes of all three horizons of the Tatarian Stage are situated inside a single section at the Vyatka River. Accordingly, this section can be considered as a type section of the entire Tatarian Stage.

Because the Vishkil' Horizon is introduced as a *nomenclature* alternative to the Severnaya Dvina Horizon, it has the same biostratigraphic substantiation. The detailed paleontological characteristics of the Severnaya Dvina Horizon was comprehensively analyzed in paleontological aspect by Olfer'ev (1974) and also in the regional stratigraphic scheme for the Upper Permian deposits adopted by the Interdepartmental Stratigraphic Commission (*Reshenie...*, 1990). It should be emphasized that the Vishkil' Horizon is defined herein not as a set of zones (i.e., by indicating its distinctive features), but by means of its stratotype (the Vishkil' Horizon is the stratotype of the Vishkil' Horizon and all coeval deposits), which can, in principle, be correlated with other sections by *any* features, both known at present and those to be revealed in the future.

AGE OF THE FLORA-BEARING BED

The plant assemblage from the Kotel'nich Locality, which has the typical late Tatarian tendency, can be reliably referred to the *Tatarina* flora (Goman'kov and Meyen, 1986). Only two taxa of this assemblage (*Algites* sp. AVG-1 and *Phyllotheca*) were not previously found in this flora. However, the occurrence of genus *Phyllotheca* was to be expected because it is represented by leaf-bearing shoots of arthrophytes, whose stems, referred to genus *Paracalamites*, are common in the *Tatarina* flora.

As for the Kotel'nich palynospectrum, it seems to be more "archaic" in comparison with other known palynospectra from the upper Tatarian Substage (taken as a combination of the Vishkil' and Vyatka horizons) due to a high content of pollen of the *Cladaitina* type. This pollen was produced by cordaites with *Rufloria* foliage (Maheshwari and Meyen, 1975), which have

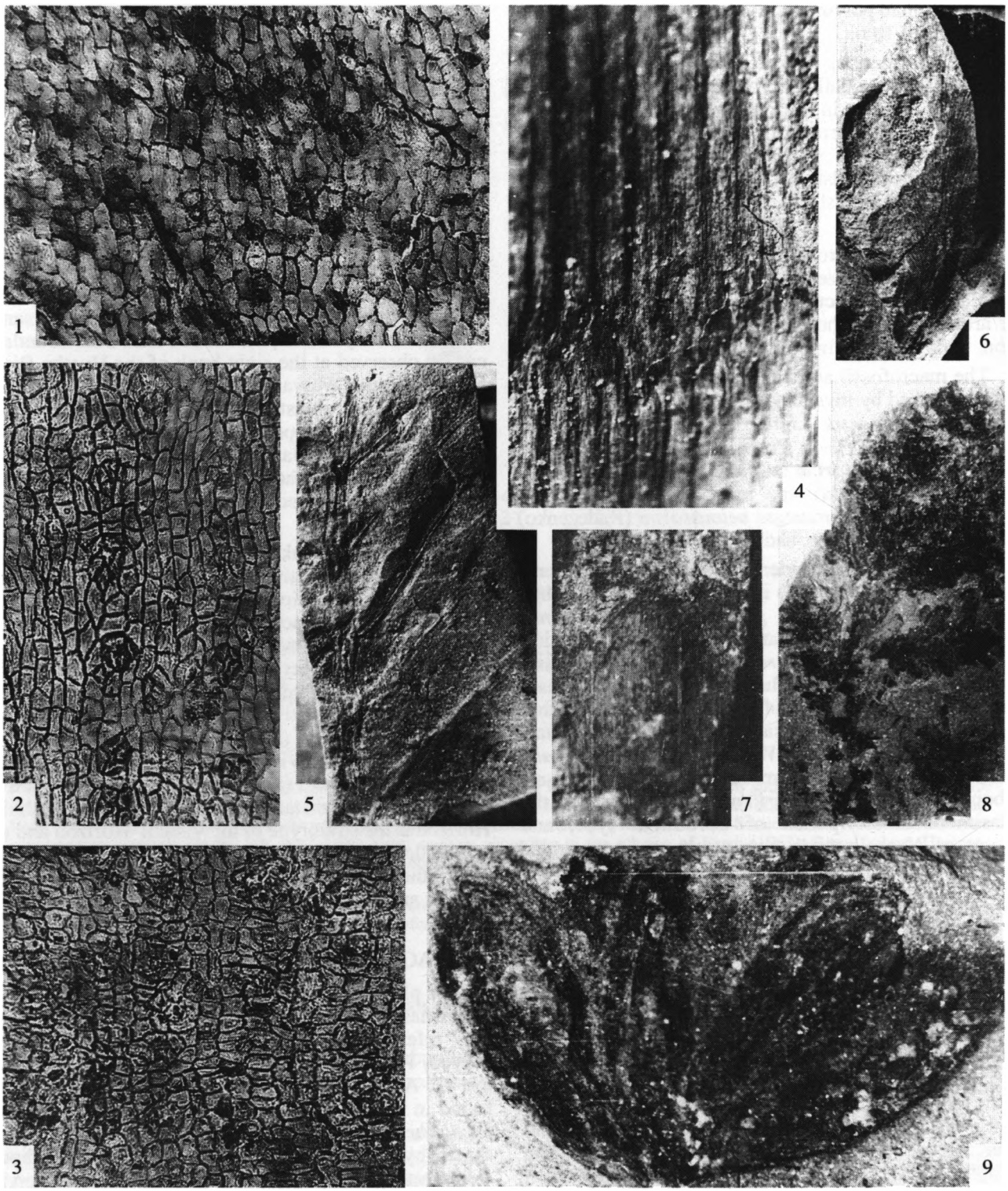


Plate I. Fossil macroplants from the Kotel'nich Locality (originals are stored at the Laboratory of Paleofloral Investigations, Geological Institute, Russian Academy of Sciences)

(1) *Phylladoderma* (*Aequistomia*) sp., leaf epidermis, slide no. 4388/675-2. ×100; (2, 3) *Tatarina conspicua* S. Meyen, slide no. 4388/675-1, ×100: (2) Upper leaf epidermis, (3) Lower leaf epidermis; (4) *Paracalamites* sp., imprint of inner surface of the pith cavity, spec. no. 4388/554, ×10; (5) *Phyllotheca* aff. *turnaensis* Gorelova, leafy shoot, spec. no. 4388/615A, ×2; (6) *Pursongia beloussovae* (Radczenko) Gomankov et S. Meyen, leaf imprint, spec. no. 4388/557, ×1; (7) *Alicospermum* sp., seed imprint, spec. no. 4388/601, ×5; (8) *Geinitzia* sp., leafy shoot moistened with alcohol, spec. no. 4388/658, ×2; (9) *Permotheca sardykense* Zalessky, synangium, spec. no. 4388/669A, ×10.

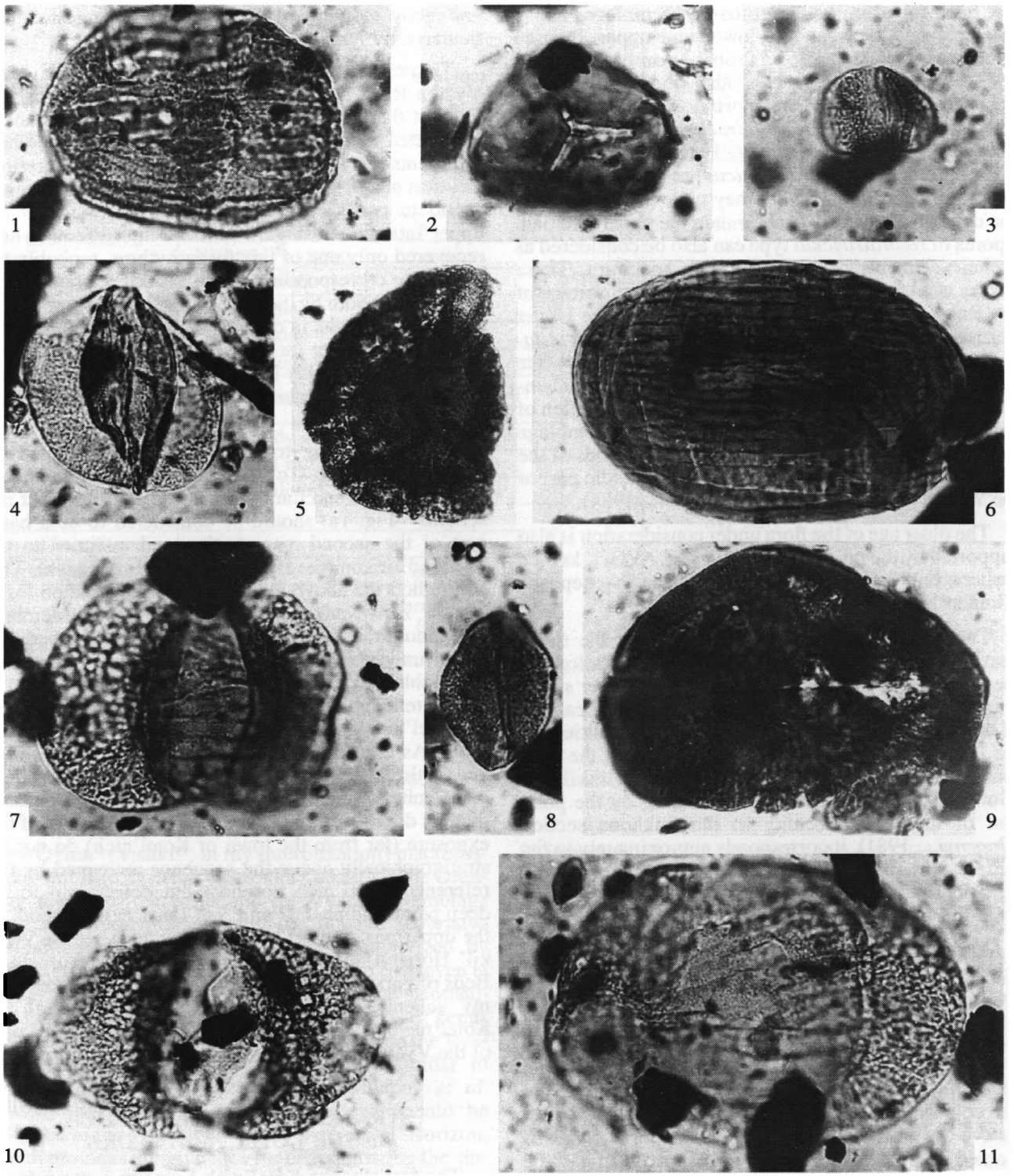


Plate II. Spores and pollen from the Kotel'nich Locality (originals are stored at the Laboratory of Paleofloral Investigations, Geological Institute, Russian Academy of Sciences).

(1) *Vittatina subsaccata* f. *connectivalis* Sauer ex Warjuchina, spec. no. 4388/507-73, ×1000; (2) *Neoraistrickia* (?) sp., spec. no. 4388/507-83, ×1000; (3) *Vitreisporites pallidus* (Reissinger) Nilsson, spec. no. 4388/507-40, ×1000; (4) *Vesicaspora arifera* (Andreeva) Hart, spec. no. 4388/507-130, ×1000; (5) *Cordaitina* sp., spec. no. 4388/507-37, ×500; (6) *Weylandites tataricus* Gomankov, spec. no. 4388/507-154, ×1000; (7) *Striatopodocarpites* sp., spec. no. 4388/507-39, ×1000; (8) *Cladaitina*(?) sp., spec. no. 4388/507-80, ×1000; (9) *Lueckisporites virkkiae* Potonié et Klaus, spec. no. 4388/507-36, ×1000; (10) *Vesicaspora* ex gr. *magnalis* (Andreeva) Hart, spec. no. 4388/507-79, ×1000; (11) *Protohaploxypinus dvinensis* (Sedova) Hart, spec. no. 4388/507-26, × 1000.

not been found in the macrofossil assemblages above the boundary between the lower and upper Tatarian substages (Kon'kov, 1967). Probably, an older age for the Kotel'nich spectrum is also indicated by the absence of pollen of *Scutasporites unicus* Klaus produced by conifers of the *Quadrocladus–Sashinia–Dvinostrobus* group (Goman'kov, 1986). These conifers and pollen of *Scutasporites unicus* are very characteristic of the *Tatarina* flora, but they were not recorded in the deposits known to be older than the upper Tatarian. Spores of *Neoraistrickia* type can also be considered as archaic elements of the Kotel'nich spectrum. These spores were not found in the upper Tatarian Substage of the Russian platform but are widespread in the Upper Permian deposits of Siberia, which also bear *Cladaitina* and *Rufloria* and are commonly dated as pre-late Tatarian. The Kotel'nich spectrum is similar in abundant pollen of *Vitreisporites pallidus* (called "pollen of caytonias" in previous publications) to the assemblage identified by N.I. Umnova from the Uglich Beds of the Kostroma area, which correspond to the middle part of the Vishkil' Horizon (*Verkhnepermskie...*, 1984).

The older age of the flora under consideration is also supported by the presence of *Algites* sp. AVG-1, known earlier only from the lower Tatarian deposits (Goman'kov, 1995).

The above-mentioned data suggest that the flora-bearing deposits near the town of Kotel'nich belong to the upper Tatarian Substage but occupy a lower stratigraphic level than all other miospore-bearing localities of the *Tatarina* flora. The oldest of these localities are the Isady at the Sukhona River (Fig. 2) and the Aleksandrovka in the Orenburg oblast, both of Vishkil' age (Goman'kov and Meyen, 1986). Judging by the position of the Isady Locality in the Sukhona section (*Opornyi...*, 1981), it corresponds approximately to the middle part of the Vishkil' Horizon. Therefore, the deposits bearing the Kotel'nich flora can be referred to the lower part of this horizon.

Although the deposits exposed at the town of Kotel'nich are situated in the stratotype region of the Tatarian Stage, their age has long been a subject of controversy (for discussion, see Ignat'ev, 1962, pp. 222–223). In recent years, these deposits were commonly assigned to the upper Tatarian Substage, but their stratigraphic position has not been precisely defined. The exposure was considered to exhibit a horizontal bedding. Therefore, a very thick sequence of the exposed deposits seemed to represent a relatively short stratigraphic interval. This made it difficult to analyze the lithostratigraphic variability of these deposits and, hence, to define their position in the composite section of the upper Tatarian Substage. It was also inferred from the horizontal bedding that the exposed part of the section was contiguous with the sequence recovered by the Kotel'nich reference hole, which revealed the boundary between the upper and lower Tatarian substages at the depth of 178 m. Such correlation between the exposed and recovered parts of the section was suggested, particularly, by Ignat'ev (1962).

Two megarhythms can be observed throughout the Vyatka River section of the upper Tatarian Substage. Each of them begins with thick sandy members and is completed with mainly fine-grained clay–carbonate sediments (clays with abundant calcareous concretions are most characteristic). These two megarhythms correspond to two (Vishkil and Vyatka) horizons of the upper Tatarian Substage. The Kotel'nich reference hole recovered only one of this megarhythms, probably the lower one corresponding to the Vishkil' Horizon. This is evidenced both by the distribution of sandy and clay–carbonate deposits in cores and by the occurrence of a limestone member (at a depth of 140–145 m) corresponding to the Filiny Beds of Forsh, the good markers inside the lower, predominantly sandy part of the Vishkil' Horizon.

Thus, according to the correlation suggested by Ignat'ev (Figs. 1b, 1c), the exposed sandy members (Members 2–4 and the lower part of Member 5 of my scheme—Fig. 1a) should be considered to be a basal part of the second megarhythm and assigned to the Vyatka Horizon (the Bykovskaya Beds of Forsh). This contradicts the above-mentioned dating based on fossil plants. However, the mapping of these members throughout the entire exposure shows that the bedding is not universally horizontal. In particular, there is a noticeable bed dip in the northern direction within the area extending from the Shabaliny Village to the town of Kotel'nich and further to the mouth of the Moloma River. As a result, the scarp in the town of Kotel'nich and further up to the Moloma mouth is composed only of Members 5 and 6. Therefore, it may be suggested that the deposits of the central and southern parts of the exposure (far from the town of Kotel'nich) do not lie stratigraphically above the sequence recovered by the reference Kotel'nich borehole but correspond to its deep parts (Members 2 and 3 of Ignat'ev), i.e., both to the uppermost beds of the sandy sequence of the Vishkil' Horizon and to the upper part of the Yurpalovo Beds of Forsh. Only the conglomerates of Member 6 of my scheme, which are exposed to the north of Kotel'nich, can be considered to constitute a basal part of the Vyatka Horizon.

STRATIGRAPHIC SIGNIFICANCE OF THE KOTEL'NICH FLORA

The fact that the Kotel'nich Locality appears to be older than almost all known localities of the *Tatarina* flora allows us to take a further step toward the refined flora-based stratigraphy of the upper Tatarian Substage.

Until recently, the early Tatarian floral assemblage of the Russian platform (the *Tatarina* flora) has been considered to be undifferentiable in stratigraphic and geographic aspects (Goman'kov and Meyen, 1986) mainly because of the similarity between the "Sever-

Sukhona River section

Scheme of N.A. Pakhtusova		Floral localities
Bed	Member	
Komaritskaya		Aristovo
Ustyug		
Gremyachevo	Temtas	
	Nizhnee Fedosovo	
Klimovo	Rovdino	Kalikino
	Erga	
	Kalikino	
Mutovino	Kichuga	
	Purtovino	Isady, Opoki, Mikulino
	Isady	Strel'na
Opoki	Strel'na	
	Mikulino	Navoloki
Nyuksenitsa		
Dmitrievo		
Verkhnyaya Toz'ma		Kopylovo II
Sharda Karpova Gora		Vostroe, Kopylovo I, Bobrovskoe
Mar'ina Gora		

Vyatka River section

horizon	Scheme of N.N. Forsh	Floral localities
Vyatka	Nefedovy	
	Bykovskaya	Mulino
Vishkil'	Kalininskaya	
	Putyatino	
	Yurpalovo	Kotel'nich
	Filiny	
	Slobodskoi	Shikhovo-Chirki
Urzhum	Syr'yany	
	Belaya Kholunitsa	
	Il'inskoe	
	Maksimovtsy	
Kazanian Stage		Shikhovo-Chirki, Donaurovo.

Fig. 2. Stratigraphic sections of the Tatarian Stage at the Sukhona and Vyatka rivers and respective floral localities.

naya Dvina" (Vishkil', in my interpretation) macrofossil assemblage from the Vyazovka Locality in the Orenburg region of the Urals and the Vyatka assemblage from the Aristovo Locality at the Malaya Severnaya Dvina River. The assemblages are characterized by common species, such as *Tatarina pinnata* S. Meyen et Gomankov and *Peltaspermopsis buevichiae* (Gomankov et S. Meyen) Gomankov (another species of genus *Peltaspermopsis*—*P.*? sp. AVG-3, known from the Vyazovka Locality only, is morphologically similar to *P. buevichiae*). As shown by Tverdokhlebov *et al.* (1989), the Vyazovka floral assemblage should be assigned to the Vyatka, but not to the Vishkil' Horizon, which provides prerequisites for differentiating the single late Tatarian assemblage and for returning to Meyen's point of view (1971) that there are two floral assemblages in the upper Tatarian Substage of the Russian platform (this opinion was stated by Meyen at the beginning of his study of the *Tatarina* flora). The lower of these assemblages (the Aleksandrovka assemblage, according to Meyen) is characterized by the presence of "sulcial" cordaites (in the Orenburg region of the Urals), *Phylladoderma* (*Aequistomia*) *rastorguevii* S. Meyen, *P.* (*A.*) *tichophora* S. Meyen, *Quadrocladus schweitzerii* S. Meyen, and peltoids with large oval seed scars (*Peltaspermopsis* sp. AVG-1), whereas the upper (Vokhma) assemblage is distinguished by peltoids with small and rounded seed scars (of *Peltaspermopsis buevichiae* type) and by taxa such as *Tatarina mira* Gomankov, *T. raristomata* Gomankov, *T. pinnata*, *T.* (?) *furcata* Gomankov, *Stiphorus biseriatus* S. Meyen, *Glossophyllum permiense* S. Meyen, *Phylladoderma* (*Aequistomia*) *aequalis* S. Meyen, *P.* (*A.*) *tatarica* S. Meyen, *Quadrocladus dvinensis* S. Meyen, and *Q. borealis* S. Meyen.

Palynospectra of these floral assemblages are also different. For example, the palynospectra from the Vyatka Horizon contain sparse pollen of *Vesicaspora arifera* (pollen of "sulcial" cordaites, see Gomankov, 1986), but there appear some new taxa unknown in the Vishkil' Horizon: *Falcisporites* sp., *Cycadopites* sp. nov., *Mulinopollenites bonus* Gomankov, *Punctatosprites* sp., and *Brevitriletes subangaricus* Gomankov.

The Kotel'nich flora may represent the third floral assemblage of the upper Tatarian Substage, which is older than both assemblages described above. The macrofossils of this assemblage lack conifers of the *Quadrocladus* type but contain abundant arthrophytes, whereas the miospore spectrum shows an absence of *Scutasporites unicus*, high content of *Vitreisporites pallidus*, relative abundance of pollen similar to genus *Cladaitina*, and the presence of spores of *Neoraistrickia* type.

A precise assignment of the Kotel'nich flora to the scheme of Forsh can promote the correlation of the stratotype section at the Vyatka River with the reference section at the Sukhona River. This correlation is of principal significance for the entire Tatarian stratigraphy (*Opornyi...*, 1981; *Verkhnepermskie...*, 1984; Goman'kov and Meyen, 1986). The Kotel'nich Locality can be considered as an analogue of the Strel'na locality at the Sukhana River, which is also characterized by abundant arthrophytes. A noteworthy fact is that both localities are associated with pure quartz sandstones, which have very limited distribution in the upper Tatarian Substage of the Russian platform. Strok (1987) suggested that these sediments were derived from the Baltic provenance in distinction to common polymictic sandstones deposited due to the activity of the Uralian rivers. Possibly, this association (the quartz sandstones and phytooryctocoenoses rich in arthrophytes) can serve as a marker horizon in the uppermost Yurpalovo Beds of Forsh and their analogues, similar to the horizon of "oxbow-lake clays" at the boundary between the Bykovskaya and Nefedovy beds (Borozdina and Olfer'ev, 1970; *Verkhnepermskie...*, 1984; Goman'kov and Meyen, 1986).

The Strel'na Locality at the Sukhona River is referred both to the Isady Member of N.A. Pakhtusova and to the upper beds of Member "a" in the scheme of the geologists of Saratov University (*Opornyi..*, 1981). The overlying Purtovino Member of Pakhtusova and Member "b" of the Saratov geologists includes the Isady Locality of the Aleksandrovka floral assemblage, which is confined to the well-known Isady lens. For these reasons, the lens can be correlated with the lenses that are exposed in the lower part of Member 5 of my scheme in the Kotel'nich area and correspond to both the uppermost Yurpalovo Beds of Forsh and the basal part of the Putyatino Horizon of Ignat'ev (1962).

Thus, the Kotel'nich floral assemblage is replaced by the Aleksandrovka assemblage slightly below the top of the Yurpalovo Beds (at the base of the Putyatino Horizon of Ignat'ev).

CONDITIONS OF PLANT BURIAL

Before discussing taphonomic aspects of the Kotel'nich Locality, it should be noted that they can be mainly defined by comparison with those of other plant macrofossil localities in the upper Tatarian Substage in the northern Russian platform. The analysis is based on the reconstruction of a general paleogeographic setting for the given space–time limits. As suggested by Strok (1987), the Moscow syneclise of the late Tatarian time was a lowland lacustrine–alluvial plain with numerous relatively small lake basins interrelated with a broad network of rivers flowing down mostly from the Urals and, to a lesser extent, from the Baltic shield. The climatic conditions of this plain are supposed to be arid (Goman'kov, 1992a; Versilin *et al.*, 1993). The geographic and stratigraphic positions of the localities mentioned below were described by Goman'kov and Meyen (1986).

The majority of the floral localities of the upper Tatarian Substage in the Russian platform can be taphonomically classified according to the degree of organic-matter preservation dependent most likely on water oxygenation, which, in its turn, is determined by the size of a basin where the burial happened, and on the distance between a locality and basin shore. The first taphonomic type is represented by localities from the horizon of "oxbow-lake clays" (except for the Mulino locality). They are confined to the dark gray or black clay–silt deposits inside thick lenses of polymictic sandstones. Abundant and diverse fossil plants of these localities are mainly represented by finely preserved phytoleims, some of them being pyritized. Evidently, these localities were formed in very small stagnant water basins with an oxygen deficiency. Oxbow lakes can serve as the most appropriate model for such basins. Contrary to the opinion of Versilin and coauthors (1993), I suppose that the sandy lenses including these localities are of alluvial genesis, because the fine preservation of the enclosed fossil plants absolutely excludes any transportation by water.

Though stratigraphically and lithologically correspondent to the same horizon of oxbow-lake clays, the Mulino locality was evidently formed under different conditions. Plant remains of this locality are more uniform (virtually leaves of genus *Tatarina* only), and phytoleims are only represented by cuticles lacking any coal matter but having well preserved morphological features. Obviously, the plants were buried in a more open and better aerated basin, but near its shore. This locality may be formed in the subsurface part of the river delta, as evidenced by the morphological features of the enclosing sandy lens with an even base and convex top. The taxonomical changes were probably caused by geobotanical factors. Vegetation of the subaerial part of the delta, which is a main component of this locality, was more uniform than that of the river valley far away from the mouth.

The third taphonomic type is represented by the Kotel'nich Locality discussed herein. Lithologically, sediments here (gray siltstone associated with "tobacco-green" polymictic sandstone) are similar to those of the previous localities; however the siltstone is not enclosed in the sandstone, but rather is contiguous

to it. Phytoleims occur very sporadically, and fossil plants are often limonitized (instead of being pyritized). All this suggests that the basin with buried fossil plants was yet more open and well aerated. This suggestion is indirectly supported by the presence of *Algites* sp. AVG-1, unusual for the *Tatarina* flora. This taxon includes algal remains, which have been known until recently from a single Kichkas Locality of the lower Tatarian in the Orenburg area. In this locality, the sediments with *Algites* sp. AVG-1 were accumulated in a very extensive basin, possibly in the ancient sea (Minikh *et al.*, 1992; Goman'kov, 1995), at a significant distance from the shore. It is also probable that the Kotel'nich Locality was formed in the peripheral part of the subsurface delta, although the "fluvial" material (gray siltstone and "snuff-colored" sandstone) is scarce here.

Finally, the fourth taphonomic type is represented by the Mikulino and Opoki Localities. There are no phytoleims. Fossil plants occur as imprints usually very fragmentary, often limonitized or covered with calcareous crusts, and preserved mainly in red mudstones or sandstones. These localities were probably formed in vast lake basins far away from the shore. The impoverished taxonomic composition of the respective floras may be due to long transportation of plant remains.

Thus, the comparative analysis of taphonomic aspects of the late Tatarian localities in the northern Russian platform suggests that the Kotel'nich Locality was formed in an extensive lake basin at a relatively short distance from the shore.

REFERENCES

Borozdina, Z.I. and Olfer'ev, A.G., Principles of Recognition of the Vyatka Horizon in the Tatarian Stage Section at the Southeastern Margin of the Moscow Syneclise, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1970, no. 1, pp. 114–120.

Efremov, I.A. and V'yushkov, B.P., *Katalog mestonakhozhdenii permskikh i triasovykh nazemnykh pozvonochnykh na territorii SSSR* (Catalogue of the Permian and Triassic Terrestrial Vertebrate Localities in the USSR), Moscow: Akad. Nauk. SSSR, 1955.

Forsh, N.N., On the Stratigraphic Subdivision and Correlation of the Tatarian Stage Sections in the Eastern Russian Platform by Means of Integrated Lithologic, Stratigraphic, Paleomagnetic, and Paleontologic Data, in *Paleomagnitnye stratigraficheskie issledovaniya* (Paleomagnetic Stratigraphic Investigations), Leningrad: Gostoptekhizdat, 1963, pp. 175–211.

Goman'kov, A.V., Taxonomic Position of the Permian Miospores, in *Teoriya i praktika palinologicheskikh issledovanii permi i triasa SSSR* (Theory and Practice Palynological Investigations of the Permian Triassic in the USSR), Available from VINITI, 1986, Syktyvkar, no. 4839-B86, pp. 4–9.

Goman'kov, A.V., Abstracts of Papers, *IV Conf. Organization Internationale de Paleobotanique, Paris, 1992, Resumes des communications*, Paris, 1992a, p. 68.

Goman'kov, A.V., The Tatarian Stratigraphy of the Vyatka River Region and Problems of the Tatarian Stage Nomenclature, *Byull. Region. Mezhved. Strartigraf. Komis. po tsentru i yugu Russkoi platformy*, 1992b, no. 1, pp. 85–87.

Goman'kov, A.V., Kitchkas Flora from the Lower Tatarian of the Southern Urals, *Paleontol. J.*, 1995, vol. 29, no. 2A, pp. 81–104.

Goman'kov, A.V. and Meyen, S.V., *Tatarinovaya flora: sostav i rasprostranenie v pozdnei permi Evrazii* (The *Tatarina* Flora: Composition and Distribution in the Late Permian of Eurasia), Moscow: Nauka, 1986.

Gubin, Yu.M., Abstracts of Papers, *Voprosy gerpetologii, VII Vsesoyuznaya gerpetologicheskaya konferentsiya, Kiev* (Problems of Herpetology, VII All-Union Conf. on Herpetology, Kiev), Kiev: Naukova Dumka, 1989, p. 70.

Ivakhnenko, M.F., A New Late Permian Dromasaur (*Anomodontia*) from Eastern Europe, *Paleontol. Zh.*, 1994, no. 1, pp. 77–84.

Ignat'ev, V.I., *Tatarskii yarus tsentral'nykh i vostochnykh oblastei Russkoi platformy, tom 1: Stratigrafiya* (The Tatarian Stage of the Central and Eastern Areas of the Russian Platform, vol. 1: Stratigraphy), Kazan: Kazan. Gos. Univ., 1962.

Kon'kov, L.V., Flora of the Upper Permian Deposits in the Orenburg and Southern Bashkiria Regions of the Urals, *Vopr. Geolog. Yuzhnogo Urala i Povolzh'ya*, 1967, vol. 4, no. 1, pp. 21–26.

Maheshwari, H.K. and Meyen, S.V., *Cladostrobus* and the Systematics of Cordaitalean Leaves, *Lethaia*, 1975, vol. 8, no. 2, pp. 103–123.

Meyen, S.V., Permian Floras from the Russian Platform and Urals Region, in *Sovremennye problemy paleontologii* (Actual Problems of Paleontology), Moscow: Nauka, 1971, pp. 294–308.

Minikh, A.V., Minikh, M.G., Pogutsa, T.I., and Goman'kov, A.V., Taphonomic Investigations of the Kichkas Locality in the Upper Permian Copper Sandstones, in *Materialy po metodam tafonomicheskikh issledovanii* (Materials on Taphonomic Methods), Saratov: Saratov. Gos. Univ., 1992, pp. 108–120.

Olfer'ev, A.G., On Correlation of the Stratotype Sections of the Upper Tatarian Substage, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1974, no. 10, pp. 123–132.

Opornyi razrez tatarskogo yarusa reki Sukhony (The Tatarian Reference Section at the Sukhona River), Saratov: Saratov. Gos. Univ., 1981.

Ochev, B.G., Enigmatic Kotel'nich, *Priroda*, 1995, no. 2, pp. 53–59.

Reshenie Mezhvedomstvennogo stratigraficheskogo soveshchaniya po srednemu i verkhnemu paleozoyu Russkoi platformy, Leningrad, 1988: Permskaya sistema (Resolution of the Interdepartmental Meeting on the Middle and Upper Paleozoic Stratigraphy of the Russian Platform, Leningrad, 1988: The Permian System), Leningrad: Vseross. Geol. Inst., 1990.

Strok, N.I., The Late Permian Lakes of the Moscow Syneclise, in: *Istoriya ozer pozdnego paleozoya i rannego mezozoya* (History in the Late Paleozoic and Early Mesozoic Lakes), Leningrad: Nauka, 1987, pp. 128–139.

Tatarinov, L.P., *Viatkosuchus sumini*—a New Therocephalian from the Upper Permian Deposits of the Perm' Area, *Paleontol. Zh.*, 1995, no. 1, pp. 84–96.

Tikhvinskaya, E.I., *Stratigrafiya krasnotsvetnykh permskikh otlozhenii vostoka Russkoi platformy: K stoletiyu permskoi sistemy 1841–1941* (Stratigraphy of Red Permian Deposits of the Eastern Russian Platform: the Centenary of the Permian System 1841-1941), *Uchen. Zap. Kazan. Univ.*, Kazan: Kazan. Gos. Univ., 1946, vol. 106, no. 4.

Tverdokhlebov, V.P. and Shminke, L.N., Eolian Formations of the Tatarian Stage in the Vyatka River Basin, *Dokl. Akad. Nauk SSSR*, 1990, vol. 315, no. 4, pp. 934–936.

Tverdokhlebov, V.P., Tverdokhlebova, G.I., and Goman'kov, A.V., Landscape Features of the Southern Urals Region in the Late Tatarian Time, in: *Paleofloristika i stratigrafiya fanerozoya* (The Phanerozoic Paleobotany and Stratigraphy), Moscow: Geol. Inst., Ross. Akad. Nauk, 1989, pp. 175–177.

Verkhnepermskie i nizhnetriasovye otlozheniya Moskovskoi sineklizy (The Upper Permian and Lower Triassic Deposits of the Moscow Syneclise), Moscow: Nedra, 1984.

Verzilin, N.N., Kalmykova, N.A., and Suslov, G.A., Large Sandy Lenses in the Upper Permian Deposits of the Northern Moscow Syneclise, *Tr. St.-Peterburg. O–va Estestvoispyt.*, 1993, vol. 83, no. 2, pp. 1–112.

V'yushkov, B.P., The Pereiasaur Locality at the Vyatka River Downstream from the Town of Kotel'nich, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1953, vol. 28, no. 2, pp. 49–56.

Stratigraphy and Geological Correlation, Vol. 5, No. 4, 1997, pp. 319–333. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 4, 1997, pp. 13–26.
Original Russian Text Copyright © 1997 by Naumov, Luzina.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

Palynoassemblages from Deposits of the Crater Lakes of the Tunguska Paleovolcanic Area

V. A. Naumov* and I. V. Luzina**

** Irkutsk State University, ul. K. Marksa 1, Irkutsk, 664003 Russia*
*** East Siberia Scientific Research Institute of Geology, Geophysics, and Mineral Deposits, ul. Dekabr'skikh sobytii 29, Irkutsk, 664026 Russia*

Received October 4, 1994; in final form, February 15, 1995

Abstract—The studied palynoassemblages were collected from the maar lacustrine sediments deposited in the upper parts of the completed pipe structures located in the south and southeast of the Tunguska paleovolcanic area. The assemblages are compared with those from the Putorana and Dvurogii phytostratigraphic horizons. As inferred, in the south and southeast of the Tunguska syneclise, the large-scale volcanism and ore-forming processes terminated in the pre-Neryunda time. Since the acritarchs, which are best adapted to water with normal (sea) salinity, are persistent components of the palynoassemblages, they can serve as indicators of pipe structures in paleovolcanic reconstructions and prospecting for iron ore.

Key words: *palynoassemblages, lacustrine deposits, ore-bearing pipe structures, volcanism, the Tunguska paleovolcanic area*

INTRODUCTION

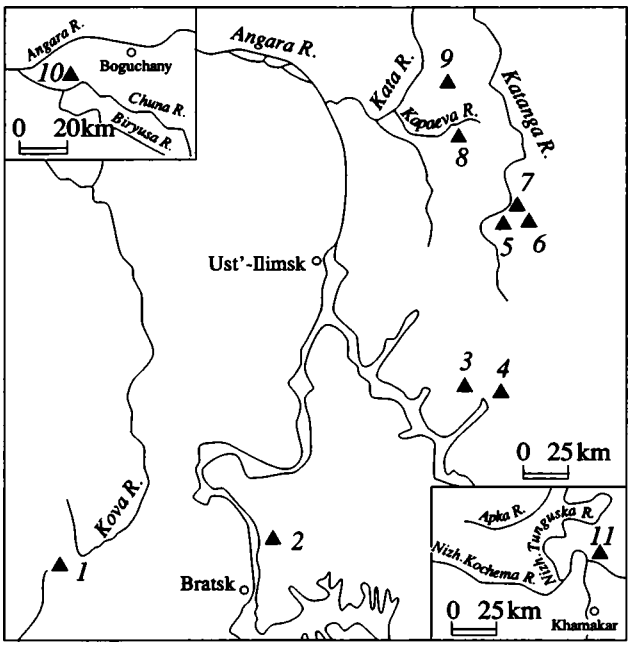
The lacustrine deposits in pipe structures, despite their high scientific interest, are the least studied geologic objects of the Tunguska paleovolcanic area, which covers a considerable part of the Tunguska syneclise. These deposits fill up the calderalike depressions or explosion funnels at the top of pipe structures, and the accumulated ground water converted them into maar (crater) lakes (Rittmann, 1960). These deposits are represented either by the sediments of crater lakes (Strakhov, 1960), or by the deposits of "bowls," the isometric basinlike synsedimentary depressions formed by post-ore sagging in the vents as a result of the consolidation of the diatreme breccia in the course of soluble component leaching by the draining ground waters (Fon-der-Flaass, 1977).

The lacustrine sediments are composed of erosion products of tuff rocks of the Korvuchana Group, eruption breccia, and scarn ores of pipe structures. The deposits are identified as the Neryunda Sequence in the Angara region (*Korrelyatsionnaya...*, 1981), the Kychet sequence in the Krasnoyarsk area of the Angara iron-ore province (Krugovykh and Kiselev, 1982), and the Inogli sequence in the upper reaches of the Nizhnyaya Tunguska River (Ankudimova and Naumov, 1986).

Nearly all of the identified lacustrine deposits are located in the well-studied pipe structures of the Angara iron-ore province in the southern part of the Tunguska syneclise: Oktyabr'skii, Materikovyi, Chitorma, Rudnaya Gora, Berikan, Moldavanka, Mara, Kapaeva, Neryunda, and Kychet Localities. Only the Inogli deposit is on the territory of the Tunguska iron-ore province in the southeast of the Tunguska syneclise (see figure). Apparently, the Korshunikha and Tat'yana deposits in the Angara province were also overlain by the crater–lacustrine sediments, which were later washed off by deep erosion (at least 600 m deep at the Korshunikha ore deposit).

Some authors identified the age of the lacustrine deposits as either the Late Jurassic–Early Cretaceous (Strakhov, 1960; 1978), or Early Cretaceous (Pukhnarevich, 1983); others referred them to the Early Triassic (Il'ina and Gutova, 1973; Krugovykh and Kiselev, 1982; Neustrueva, 1984; Polyakova and Vishnyakova, 1984; Naumov *et al.*, 1988), or Early-Middle Triassic (Odintsova *et al.*, 1980). The age of maar deposits is important for fixing the time of termination of ore processes in pipe structures, because lacustrine sediments contain beds of clastogenic martite–magnetite ores. The age aspect is no less important for prospecting new ore deposits. A few researchers (*Angaro–Vilyuiskii...*, 1980) maintain that in the region under study "the geologic time (Early Jurassic–Early Cretaceous) of ore formation does not coincide with the Permian–Triassic time of plateau basalt intrusions into the sedimentary cover."

The results of palynological studies of lacustrine sediments in the Oktyabr'skii, Kapaeva, Neryunda, and Materikovyi ore deposits, and in the Chitorma and Inogli ore manifestations, are described below.



The scheme of localites of the maar lacustrine deposits in pipe iron-ore structures in the south and southeast of the Tunguska paleovolcanic region. Deposits of the Angara iron-ore province: (*1*) Oktyabr'skii; (*2*) Materikovyi; (*3*) Rudnaya Gora; (*4*) Chitorma; (*5*) Berikan; (*6*) Moldavanka; (*7*) Mara; (*8*) Kapaeva; (*9*) Neryunda; (*10*) Kychet. The deposit of the Tunguska iron-ore province: (*11*) Inogli.

SPECIFIC STRUCTURAL FEATURES OF LACUSTRINE SEDIMENTATION

The sediments in question are confined to the craters of the largest and least eroded pipe structures of the iron-ore deposits. On the surface, they overlie rocks of ore-bearing polycyclic diatremes, the roots of which reach the Lower Cambrian carbonate–evaporite sequence (Fon-der-Flaass, 1992). In the plan view, the bowls are rounded, elipsoid, isometric, or slightly elongated. The rims are steeply inclined towards the center.

Every pipe has its own specific structure. For example, at the Kychet deposit, only 155.4 m of the 500-m-thick lacustrine sediments are composed of conglomerate breccia and poorly graded gravelites. In the lacustrine sequence of the Ignoli ore manifestation, almost the entire 375 m of the exposed section contain volcaniclastic siltstones.

At the Neryunda deposit, the lacustrine sediments are traced to a depth of 220 m. Ore-bearing sandstone and slump breccias form the base of this section, the larger part of which is composed of alternating volcaniclastic siltstones and sandstones with considerable admixture of coaly material.

In the Kapaeva deposit, lacustrine sediments are 720 m thick, thus being the thickest yet discovered. Their base is built up of ore-bearing sandstone and collapse breccias. Upsection, the layers are composed of alternating volcaniclastic sandstones and siltstones with intercalations of their breccia and interbeds of sandy gritstone, ore-bearing gravel-gruss conglobreccia, and rhythmically alternating volcaniclastic coarse-grained sandstones and siltstones. The upper part of the section is composed of volcaniclastic siltstones with separate intercalations of volcaniclastic sandstones. The section includes abundant plant detritus and small brown coal lenses and has a high content of concretions.

The thickness of lacustrine sediments at the Oktyabr'skii deposit is 690 m, and volcaniclastic sandstones and siltstones form the bulk of the sequence here. Thin interbeds of sandy gravel–gruss breccia conglomerates, containing ore and other components, appear at the base and in the middle of the section. The middle and upper parts have horizons of volcaniclastic gravel sandstones.

The studied lacustrine deposits at the Chitorma ore manifestation are 560 m thick. The clastogenic ores 12- to 30-m thick lie at the base of the section, the main part of which is built up of laminated volcaniclastic siltstones and sandstones with beds of sandstone breccia and gravel–gruss conglobreccia. The interval of 0–85 m is composed of dolerite and sandstone, clayey Quaternary deposits with bedrock thalus.

The main peculiarity of lacustrine sediments at the Materikovyi ore deposit is the abundance of clastogenic ores. About 230 m of the 470-m-thick lacustrine section is composed of magnetitic sandstones. The section also includes considerably smaller amounts of gravel–gruss conglobreccia, magnetite-containing volaniclastic sandy gritstones, sandstones and siltstones, sandy magnetitic limestones and calcarenites. These rocks occur at different levels, and the whole volume of the bowl is potentially ore-bearing. Slump breccias are observed in the middle part of the section. Another peculiarity of the Materikovyi deposit is the presence of large lenses and beds of intact volcanic clastic rocks such as tuffs, explosion breccias, and tuffites. The section also lacks the rhythmically layered volcaniclastic sandstones and siltstones typical of other deposits. Only several intervals of massive tuffaceous siltstones with plant imprints similar to those in the Neryunda sequence stratotype were observed. The rhythmically deposited rocks form separate intercalations at different levels in the sequence; they are composed of alternating layers of specific rocks such as volcaniclastic sandstones with magnetite, sandy magnetite calcarenites, chemogenic limestones, tuffites with magnetite, and magnetitic sandstones.

The characteristic feature of all these lacustrine sediments is the high content of carbonate cement sometimes responsible for their transition into clastic–carbonate and carbonate rocks. The frequent sagging of the bowl deposits produced roiling and slumping of sediments, distortion of bedding, repeated formation of breccias of unconsolidated or poorly consolidated

sediments, and triggered the inflow of coarse clastic material. The abundant postsedimentary tectonic breccias compose members differing in thickness and position. The lacustrine sediments of the Chitorma deposit and the Materikovyi ore manifestation experienced the greatest dislocations.

PALYNOCOMPLEXES OF LACUSTRINE DEPOSITS

The deposits of crater lakes and their palynoassemblages were studied at the Palynological Laboratory of the East Siberia Scientific Research Institute of Geology, Geophysics, and Mineral Resources, and at Irkutsk State University, from 1979 to 1985. The microfossils were identified by L.A. Ankudimova, I.V. Luzina, and V.L. Penigina. The total of 626 samples, recovered from lacustrine deposits, were analyzed, and 360 of them contained spores and pollen. Based on the evidence of the general composition and the relationship between the main taxa, the obtained spore–pollen spectra represent four Lower Triassic palynoassemblages.

The oldest palynoassemblage was collected from the Inogli deposits in the upper reaches of the Nizhnyaya Tunguska. The high pollen content of *Gnetaceaepollenites* genus in the spectra is a characteristic feature of this palynoassemblage. Pollen of *Disaccites* and structural *Azonaletes* is subdominant. The ribbed pollen of conifers is accessory: *Taeniaesporites* sp., *Striatopodocarpites* sp., *Lueckisporites* spp., fam. Podocarpaceae, *Zonaletes restrictus* Andr). Spores represent a considerable number of paleophytic species: *Turrisporites sibiricus* (Medv.) Lub., *Nigrisporites marginatus* (Portn.) Drjag., *N. nigritellus* (Lub.) Oschur., *Trachytriletes tumulosus* (Andr.) Drjag., *Raistrickia cornuta* (Andr.) Lub. et Dibn., and *Granulatisporites facerus* (Andr.) Lub.

Moreover, there are numerous mesophytic species of spores: *Naumovaspora striata* Jans., *Concavisporites* sp., *Punctatisporites limpidus* War., *Stenozonotriletes bellus* War., *Apiculatisporis levis* Balme et Henn., and also such taxa as *Nevesisporites limatulus* Playf., *Osmundacidites* sp., and *Kraeuselisporites* sp., which appear in the Upper Permian beds of Eurasia and which, in association with *Punktatisporites, Calamospora,* and *Marattiaporites*, constitute the reference taxa in the pollen assemblage of the first half of the Lower Triassic (Romanovskaya and Vasil'eva, 1990).

The quantitative correlation of myospores reveals three subassemblages in the depth intervals of 273.7–368.0, 140.6–273.7, and 28.0–140.0 m (Table 1).

In the first subassemblage (depth interval of 273.7–368.0 m), pollen of *Gnetaceaepollenites* sp. (30–45%) dominates, and the coniferous pollen of *Disaccites* and of structural *Azonaletes* is subdominant, whereas among the accessory elements there are *Vitreisporites* sp., *Taeniaesporites* sp., *Lueckisporites* sp., *Platysaccus* sp., *Microcachryidites* sp., *Zonaletes restrictus* Andr., and *Cordaitina* spp.

Table 1. Correlation of subassemblages of the Inogli Sequence*

List of taxa	S/A-I 10%	S/A-I 30%	S/A-II 10%	S/A-II 20%	S/A-III 10%	S/A-III 30%
Nevesisporites sp.						
Naumovaspora striata						
Raistrickia-neoraiscria						
Caliendrina sp.						
Apiculatisporis levis						
Other spores						
Vitreisporites sp.						
Yinkgocycadophytus sp.						
Platysaccus sp.						
Disaccites						
Triadispora sp.						
Lueckisporites spp.						
Ribbed coniferous						
Ynetaceaepollenites sp.						
Azonaletes (structural specimens)						
Taeniaesporites spp.						
Zonaletes-restrictus						
Cordaitina sp.						
Acritarchs						

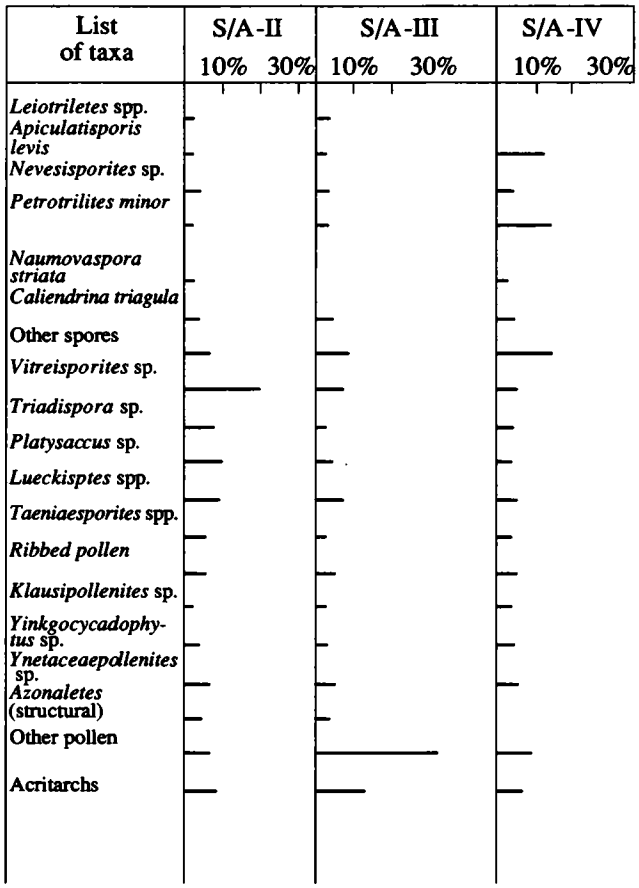
Note: *The acritarchs percentage is calculated relative to the total number of microfossils.

The paleophytic species listed above constitute the larger part of the spores. The share of mesophytic forms *Naumovaspora striata* Jans., along with spores of *Nevesisporites* sp., and *Osmundacidites* sp., is not large. There are single finds of *Concavisporites* sp., *Stenozonotriletes bellus* War., *Laphotriletes minutepunctatus* Bolch., *Apiculatisporis levis* Baime et Henn., and a certain number of *Veryhachium.*

The second subassemblage, collected from a depth interval of 140.6–273.7 m, has a greatly reduced the content of pollen of the genus *Gnetaceaepollenites* and a larger share of coniferous ribbed pollen: *Taeniaesporites* sp., up to 15% and *Lueckisporites* sp., up to 10%. The spore fraction is depleted in paleophytic species. Of the latter, only few specimens of *Turrisporites sibiricus* (Medv.) Lub., *Nigrisporites nigritellus* (Lub.) Oschur., *N. marginatus* (Portn.) Oschur., *Raistrickia* sp. and the pollen of cordaiteans were found.

The third subcomplex was obtained from a depth interval of 28–140 m, where the relationship between spores and pollen is changed. Among spores, the most

Table 2. Correlation of subassemblages of the Neryunda Sequence*



Note: * The acritarchs percentage is calculated relative to the total number of microfossils.

frequent are *Raistrickia* sp., *Neoraistrickia* sp., *Nevesisporites* sp., and *Naumovaspora striata* Jans.; there are fewer *Osmundacidites* sp., *Acanthotriletes* sp., and *Lophotriletes* sp., whereas the paleophytic species are almost entirely lacking. There is a somewhat greater amount of *Zonaletes restrictus* Andr. and *Cordaitina* sp. pollen than in the second subassemblage, but on the whole the composition is the same. Acritarchs are more abundant than in the first two subassemblages.

The palynoassemblage of the Inogli deposits is similar to that of the Limptekon Formation on the Ilimpei River and to that in the upper part of the Bugarikta Formation in the middle reaches of the Nizhnyaya Tunguska (Yaroshenko, 1967), because they all show the high content of *Gnetaceaepollenites* sp. pollen associated with spores of *Naumovaspora striata* Jans. and *Nevesisporites* sp., the echinulate *Osmundacidites* sp. and *Apiculatisporis* sp., and pollen of *Vitreisporites* sp., conifers and cordaiteans. This palynoassemblage is peculiar by virtue of a large content of paleophytic myospores and a smaller number of *Vitreisporites* sp.. The high amount of *Gnetaceaepollenites* sp. spores and the presence of *Lueckisporites* spp., *Taeniaesporites* sp., and *Naumovaspora striata* Jans. correlate this palynoassemblage with palynoflora of the Irgakta Member of the Bugarikta Formation in the central part of the Tunguska basin and with that of the upper beds of the Korvunchana Formation exposed in the middle reaches of the Nizhnyaya Tunguska (Romanovskaya *et al.*, 1973; Krugovykh, 1978, 1983). However, the palynoassemblage is distinct because of the presence of paleophytic species, which date it back to an earlier period.

In the Central Angara region, mesophytic palynoassemblages were collected from the Neryunda sequence of the Neryunda, Kapaeva, Oktyabr'skii, and Materikovyi ore deposits and at the Chitorma ore manifestation. In these localites, the second, third, and fourth palynoassemblages are identified by the composition of their spectra (Table 2).

The second complex was obtained from the core of Well 46, the Neryunda deposit (depth interval of 60–120 m); from wells 29 and 32, the Oktyabr'skii deposits; and from Well 60, the Materikovyi deposit. The pollen of *Disaccites* dominates here, whereas *Vitreisporites* sp., *Platysaccus* spp., *Triadispora* sp. and diverse *Lueckisporites,* and *Taeniaesporites* forms are subdominant. Among the accessory components there is pollen of *Azonaletes* with structural exine and specimens of *Gnetaceaepollenites* sp. and *Ginkgocycadophytus* sp.

Spores in the assemblage are not abundant (up to 15%). Most frequent are spores of *Nevesisporites* sp. and *Leiotriletes* spp., while echinulate *Apiculatisporis levis* Balme et Henn., *Osmundacidites* sp., *Capilatisporites variabilis* (Portn.) Rom., calamites *Calamospora* sp., *Punctatisporites* sp., and *Caliendrina triangula* Mal. with rugose exine are subordinate. In addition, there are single specimens of *Stenozonotriletes bellus* War., *Punctatisporites limpidus* War., *Naumovaspora striata* Jans., *Camarozonotriletes* sp., *Trachytriletes* sp., *Perotrilites minor* (Mädl.) Ant. et Taug.-Lantz., *Conglomeratispora triassica* (Mal.) War., and *Danaeopsites* sp.

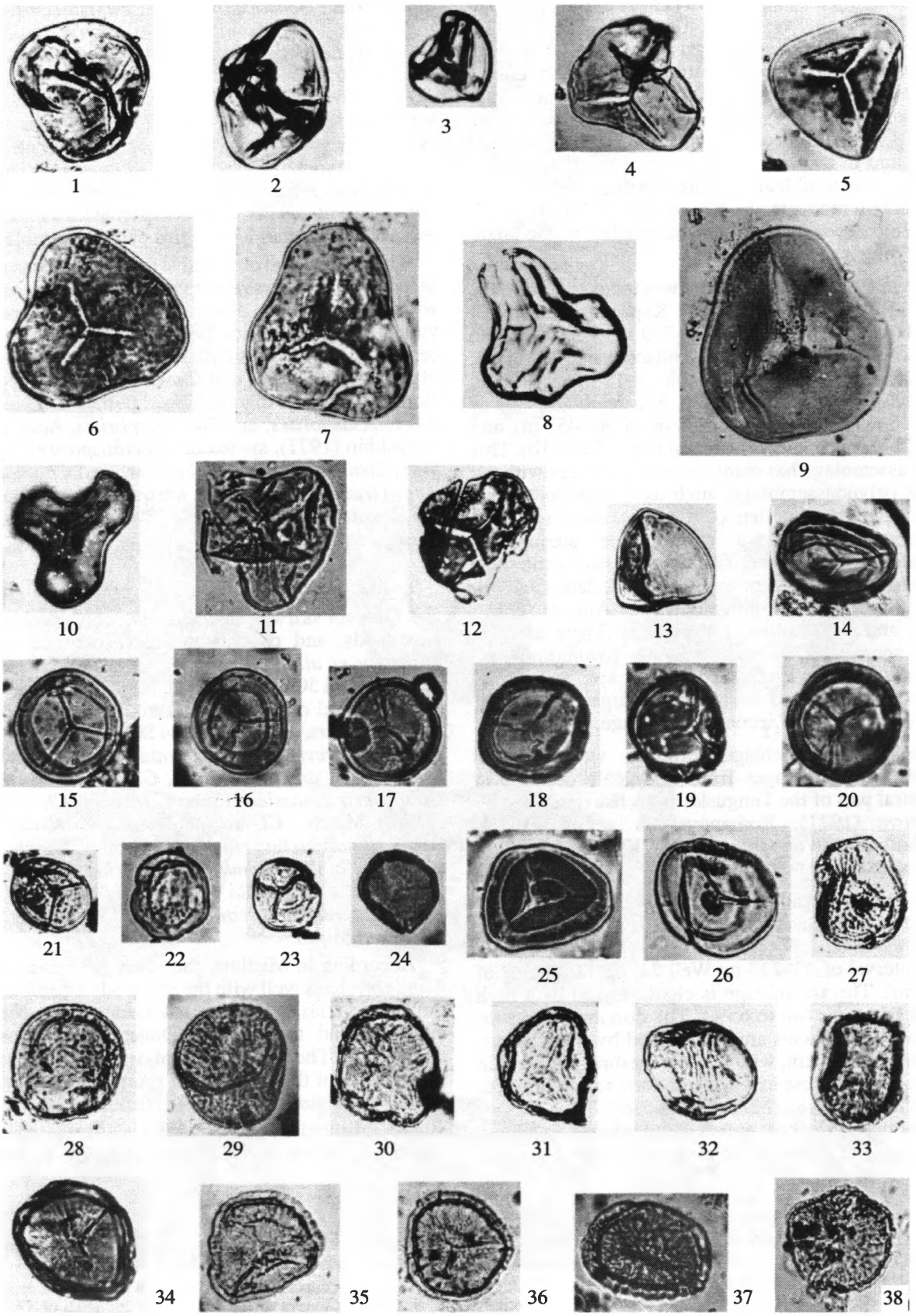
The acritarchs *Baltisphaeridium, Veryhachium,* and *Leiofusa* are found in all palynological spectra.

Plate I. Spores from the deposits of the Neryunda sequence (magn. 600).

(1, 2) *Dictyiphyllidites harrissii* Coup.; (3) *Dictyophyllidites* sp.; (4–8) *Cyathidites* spp.; (9–11) *Cyathidites microreticularis* Rom.; (12) *Cyathidites* spp.; (13) *Leiotriletes* sp.; (14–20) *Nevesisporites* spp.; (21–24) *Nevesisporites limatulus* Pl.; (25, 26) *Chomotriletes* sp.; (27–32) *Naumovaspora striata* Jans.; (33–38) *Perotrilites minor* (Mädl.) Ant. et Taug.-Lantz.

(1–20) Well 3, depth interval of 147–318 m, Kapaeva deposit; (21–32) Well 46, depth of 128 m, Neryunda deposit; (33–38) Well 3, depth of 147 m, Kapaeva deposit.

Plate I


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38

The palynoassemblage under discussion is similar to that identified by Kurbatova (1971) in the upper part of the Korvunchana Formation on the Vivi River. Obonitskaya (1973, 1974) recorded a high content of *Vitreisporites* sp., a considerable number of grains of *Lueckisporites* spp. and *Gnetaceaepollenites* sp., and identified spores of *Punctatisporites* sp. and *Cyathidites* sp. in the Irgakta sequence of the Nizhnyaya Tunguska region and in the Pirda Formation of the Eika region. This palynoassemblage is similar to the Lower Triassic assemblages recovered by Krugovykh (1978) from volcanogenic deposits in the middle reaches of the Nizhnyaya Tunguska.

The third palynoassemblage was recovered from the cores of wells drilled at the Kapaeva ore deposit (Well 1G, depth interval of 310–379 m; Well 24, depth interval of 240–355 m; Well 6, depth interval of 80–130 m; Well 202, depth interval of 187.3–193.0 m) at the Oktyabr'skii ore deposit (Well 50, depth interval of 447–646 m; Well 26, depth interval of 96–455 m), and at the Chitorma ore manifestation (wells 3 and 10). This pollen assemblage has many common features with the second palynoassemblage, such as a high content of ribbed coniferous pollen of *Lueckisporites* spp. and *Taeniaesporites*, and a considerable amount of *Platysaccus* sp. However, it shows a lower content of *Vitreisporites* sp. pollen, but more abundant *Caliendrina* sp., *Perotrilites minor* (Mädl.) Ant. et Taug.-Lantz., and *Nevesisporites* sp. spores. There are also single spores of *Leiotriletes* spp., *Cyathidites* sp., *Osmundacidites* sp., *Densoisporites* sp., and *Kraeuselisporites* sp., and a somewhat larger number of acritarchs than in the second assemblage.

This palynoassemblage correlates well with the mesophytic assemblages from tuffogenic deposits in the central part of the Tunguska syneclise described by Kurbatova (1971), Romanovskaya *et al.* (1973), Tabachnikova and Dryagina (1973); Krugovykh (1978, 1983), and Obonitskaya (1974).

The fourth palynoassemblage is recovered from the upper part of the lacustrine section at the Kapaeva ore deposit (Well 3, depth interval of 24–200 m; Well 1G, depth interval of 43–223 m; Well 24, depth interval of 9–214 m). The assemblage is characterized by a high content of spores (up to 65%). The dominant and subdominant components are represented by small forms, not more than 30 μm, with a trilete laesura, narrow thin perispore, and rugose exine. These forms are referred to *Perotrilites minor* (Mädl.) Ant. et Taug.-Lantz., whereas the echinulate spores are attributed to *Apiculaîisporis levis* Balme et Henn. Accessory components are spores of *Nevesisporites* sp., *Capilatisporites variabilis* Rom., *Densoisporites* sp., *Punctatisporites limpidus* War., *Stenozonotriletes bellus* War., *Calamospora* sp., *Leiotriletes* sp., *Conglomeratispora triassica* (Mal.) War., *Chomotriletes redunciformis* Korot., and pollen of *Triadispora* sp., *Falcisporites* spp., *Protohaploxypinus* sp., *Alisporites* sp., *Chordasporites* sp., and *Microcachryidites*. There is a considerable amount of diverse striated pollen of *Lueckisporites* and *Taeniaesporites* genera, pollen of *Gnetaceaepollenites* and *Ginkgocycadophytus*, and a somewhat lesser number of acritarchs here than in the third palynoassemblage.

The assemblage obtained is peculiar and has no analogues among others reported so far. It can be compared with the mesophytic assemblages from the upper Korvunchana Subformation and Nidym Formation of the central part of the Tunguska syneclise by the presence of *Nevesisporites* sp., and *Chomotriletes redunciformis* Korot. spores and diverse ribbed pollen of the coniferous *Lueckisporites*, and *Taeniaesporites*. According to Varyukhin (1971), spores of *Punctatisporites limpidus* War., *Stenozonotriletes bellus* War., and *Conglomeratispora triassica* (Mal.) War. are quite common in Triassic deposits of the northeast of European Russia.

Plates 1–5 show the main taxa identified in the studied palynoassemblages.

The lacustrine deposits of the Kapaeva, Neryunda, and Oktyabr'skii ore deposits also contain ostracods, gastropods, and conchostracans. From our samples (Naumov *et al.*, 1988), collected at the Oktyabr'skii deposit (Well 50, depth interval of 149–471 m; Well 26, depth interval of 111.3–452.0 m), Mishina macerated ostracods *Darwinula obruchevi* Schn., *D. postparalella* Misch., *D. brevis* Misch., *D. lenta* Schn., *D. lata* Mand. et Neust., *D. angulata* Mand., *Gerdalia clara* Misch., *Clinocypris triassica* (Schn.) Misch., *Cl. elongata* (Schn.) Misch., *Cl. scolia* Mand., *Pulviella ovalis* Schn., *Triassinella chramovi* (Schn.) Misch., *Lutkevichinella* aff. *minima* Star., *Glorianella* aff. *mirtovae* Schn., *Kostromella* aff. *solubris* Misch., *Nerechtina plana* Misch., *N. cordata* Misch., and *Wetluginella* cf. *optata* Misch.

According to Mishina, the entire ostracode assemblage correlates well with the ostracode assemblages of the Lower Triassic Baskunchak Group in the Moscow syneclise and the Dnieper–Donets and Pericaspian depressions. The composition of ostracode species varies throughout the section and shows the lake basin as unstable in water salinity and in depth.

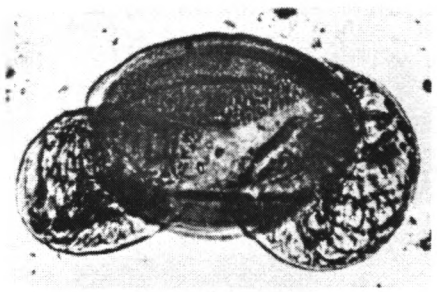
As indicated by Neustrueva (1984), the dominant ostracode species derived from lacustrine deposits at

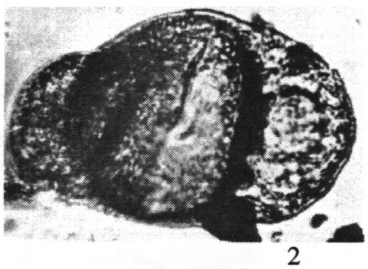
Plate II. Pollen from the deposits of the Neryunda sequence (magn. 600).

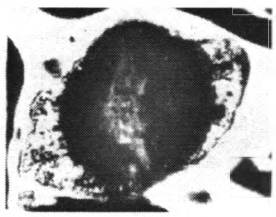
(1–4) *Platysaccus* spp.; (5) *Minutosaccus* spp.; (6, 7) *Minutosaccus potoniei* Maed.; (8–13) *Klausipollenites schaubergeri* Pot. et Klaus.; (14) Coniferae; (15) *Illinites* sp.; (16) *Scopulisporites* sp.; (17) *Chordasporites singulichorda* Klaus.

(1, 2) Well 46, depth of 128 m, Neryunda deposit; (3, 5–8, 11–14, 16, 17) Well 3, depth interval of 265–318 m, Kapaeva deposit; (4) Well 24, depth of 101 m, Kapaeva deposit; (9–10) Well 3, depth of 147 m, Kapaeva deposit; (15) Well 26, depth of 37.7 m, Kapaeva deposit.

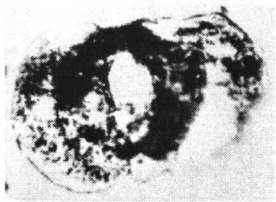
Plate II


1

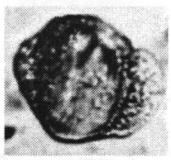

2

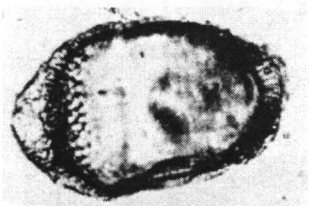

3

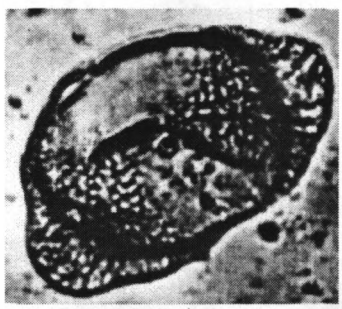
6


4

5

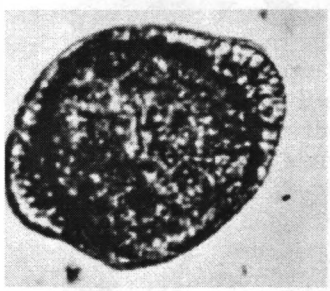

7

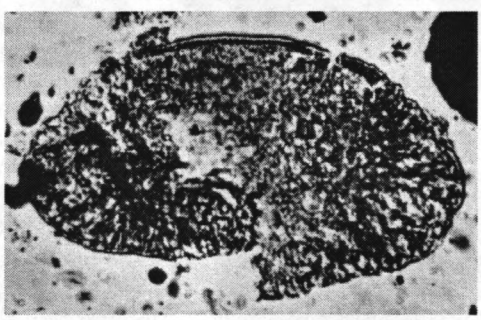

8


9

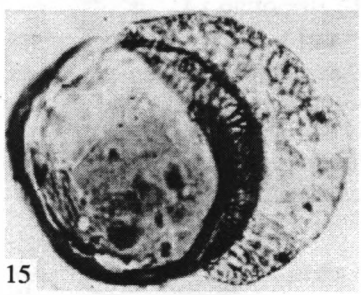
10

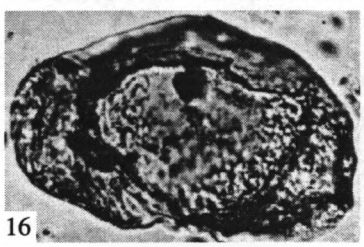
11


12


13

14


15


16

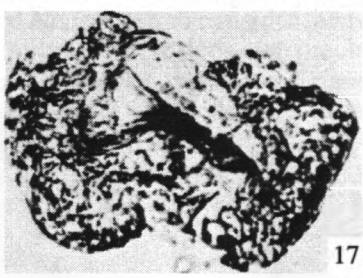
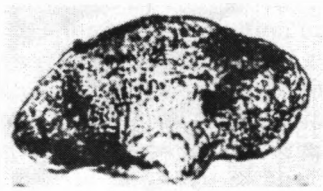
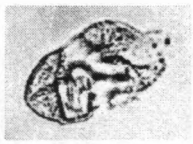
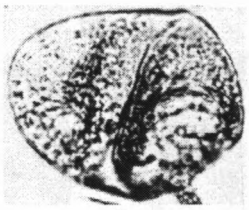
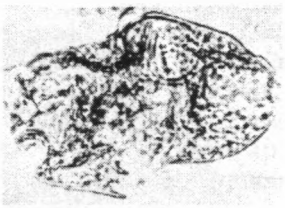

17

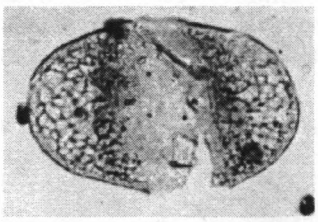
Plate III

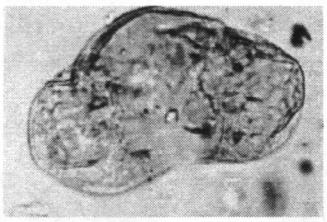

1

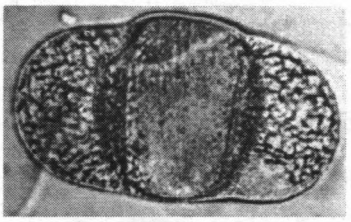

2

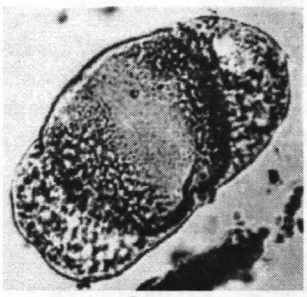

3

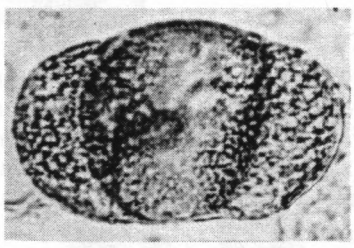

4

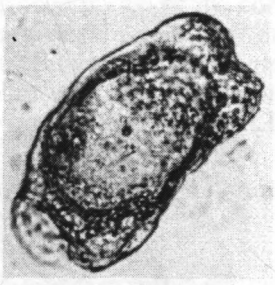

5

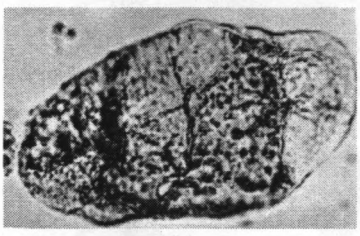

6

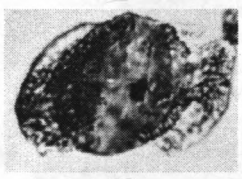

7

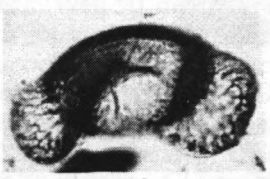

8


9

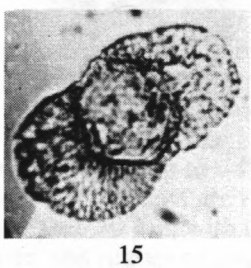

10

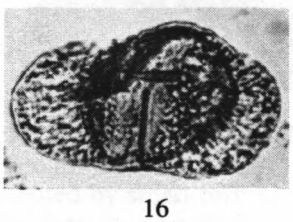

11

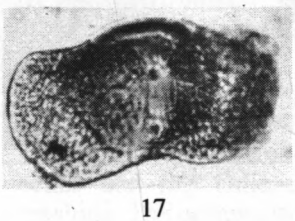

12

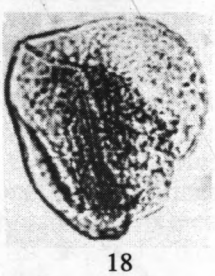

13

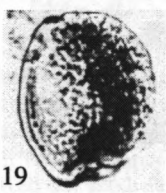
14

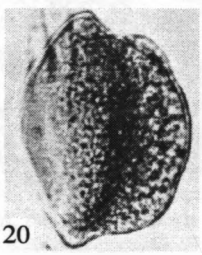

15

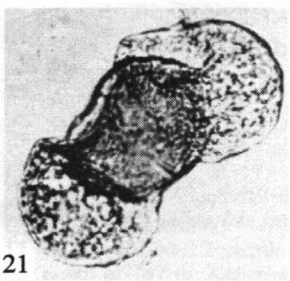

16


17


18


19


20


21

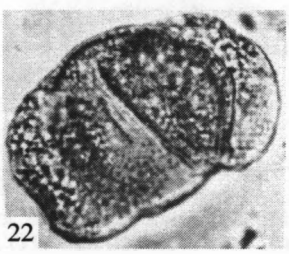

22

Table 3. Correlation scheme of volcanites in the south and southeast of the Tunguska paleovolcanic region

Period	Series	Stage	Horizon	Central Angara Region		Upper reaches of the Nizhnyaya Tunguska
Triassic	Lower	Induan–Olenekian	Putorana			Chaikokon Sequence
						?
				Neryunda Formation		Inogli Sequence
		Induan	Dvurogii	?		
						?
Permian	Upper	Tatarian	Gagarii ostrov	?		Kochema Formation
				Kapaeva Formation:	Edarma Member	
					Zelinda Member	Kholok Formation
					Nevon Member	
				?		?

the Oktyabr'skii (Well 50, depth interval of 23.0–529.6 m), Kapaeva (Well 1G, depth interval of 34.0–387.5 m) and Neryunda (Well 19, at 44.5-m level) ore manifestations are identical to those obtained from the Lower Triassic deposits of the Kuznetsk basin (Kedrovskii Horizon of the Mal'tsevo Formation) and Tunguska syneclise (the upper Korvunchana Subformation), and from the Vetluga Group of the Russian platform and Pericaspian depression, where the ostracode group includes *Darwinula angulata* Mand., *D.* ex gr. *inassueta* Misch., *D.* ex gr. *ulrichi* Misch., *D.* ex gr. *lacrima* Star., *D. radczenkoi* Mand., *D. minuta* Mand., *Gerdalia clara* Misch., *G.* aff. *wetlugensis* Bel., *G.* sp., *Suchonella* ex gr. *curvidorsalis* Mand., *S.* aff. *apposita* Mand., *S.* aff. *circula* Star., *S. constricta* Neustr., *S.* aff. *rycovi* Star., *S.* ex gr. *stabilis* Neustr., *Darwinuloides* ex gr. *longus* Misch., *D-s oviformis* Mand., *D-s* sp.

In Well 50, below the level of 177.8 m, the Early Triassic species are recovered in association with *Darwinula arctica* Lev and *Darwinuloides* ex gr. *alveatus* Lev, the latter first identified in the Upper Permian of the Misailap Formation in the Nordvik Region. The Early Triassic forms, however, dominate in this interval, and only the Early Triassic species *Darwinula angulata* Mand. and *Suchonella* aff. *circula* Star. from the depth interval of 528.9–529.6 m are represented by fewer specimens. Moreover, the studied samples also contain *Darwinula* ex gr. *casta* Misch. and *D.* ex gr. *frivolis* Mand., reported from the Upper Permian deposits of the Degali Formation in the Nizhnyaya Tunguska basin and from the Tailuga Formation in Kuznetsk basin.

A few individual ostracode species typical of the Upper Permian Sequence (the Upper Tatarian Stage) of the Misailap Formation in the Nordvik region—*Darwinula arctica* Lev., *D. fragiles var minima* Lev., *Darwinuloides* ex gr. *alvcatus* Lev.—were collected from Well 19 at the Neryunda ore deposit and from Well 1G at the Kapaeva ore occurrence. The restricted number of species allowed Neustrueva to consider them as surviving Permian forms, which does not preclude the attribution of the host beds to the Lower Triassic. The taxonomic composition of ostracodes and the peculiar features of their oryctocoenoses testify that they inhabited highly mineralized lakes.

Plate III. Pollen from the deposits of the Neryunda sequence (magn. 600).

(1, 2) *Vitreisporites pallidus* (Reis.) Nils.; (3) *Vitreisporites koenigswaldii* Jans.; (4–6) *Vitreisporites* spp.; (7–11) *Falcisporites stabilis* Balme.; (12–14) *Triadispora forma* Jans.; (15, 16) *Triadispora plicata* Klaus.; (17–22) *Triadispora* spp.

(1–6, 15) Well 3, depth 147 m, Kapaeva deposit; (7–14, 16–22) Well 46, depth 128 m, Neryunda deposit.

In the cores of wells 50 and 26 of the Oktyabr'skii ore deposit, Polyakova (Polyakova and Vishnyakova, 1984) identified conchostracans *Tripemphigus* cf. *khovorkiliensis* Nov., *Limnadia komiana* Mol., *L.* cf. *ovata* Nov., and *Estheriina* sp. previously recovered from the Lower Triassic Vetluga Group of the Russian platform.

The lacustrine sediments of the Oktyabr'skii deposit also bear gastropods, the larger part of which is endemic. Vishnyakova has established two gastropod horizons here. The upper horizon is characterized by the presence of *Bithynia* (?) sp. and *Valvata octoberiana* Vish., and the lower one by *Valvata scobloi* Vish. The boundary between the horizons in Well 50 of the Oktyabr'skii deposit lies at a depth of 184 m.

Almost all samples contain gyrogonites of charophytes belonging, according to Romashkina, to the *Porochara.* genus, which is distributed throughout the Carboniferous–Jurassic interval. In an oral presentation, however, Romashkina noted that the collection recovered from Well 50 had none of the elements of Cretaceous charophytes.

The core from Well 50 (depth interval of 100–400 m) at the Oktyabr'skii deposit contains plant imprints. As stated by Mogucheva, most of them belong to the *Cladophlebis* sp. The upper part of a leaf of *Taeniopteris* sp. and seeds of *Carpolithes* ex gr. *minor* Pryn. and *Arthropsida* gen. et sp. ind. were also identified here. The remains, though extremely fragmentary, comply with the Early Triassic age of the enclosing rocks.

The larger part of the vegetal remains recovered from Well 1G (depth interval of 45.5–378.8 m) also belongs to *Cladophlebis* sp. Other remains likewise collected are *Lepidopteris* cf. *arctica* Mog., *Peltaspermum* sp., *Carpolithes* sp., *Cladophlebis* ex gr. *margoserzata* Mog., *Katasiopteris* sp., *Elatocladus* cf. *linearis* Pryn.

As assumed by Mogucheva, the listed forms imply the Early Triassic age of the enclosing rocks. In the Tunguska basin, the *Elatocladus linearis* Pryn. species was found in the Dvurogii and Tutonchany horizons, whereas *Lepidopteris arctica* Mog. was observed in the Induan and lower Olenekian deposits of Eastern Taimyr. According to the data of Sadovnikov (1981a), *Lepidopteris arctica* Mog. is one of the vegetal remains typical of the Fad'yu-Kuda Formation in that area and is the Early Triassic (Induan–early Olenekian) in age. In the western Verkhoyansk area and on Taimyr, this species forms a part of the two postpaleophytic floral assemblages of the Early Triassic (early Induan, Induan–Olenekian) (Sadovnikov *et al.*, 1981).

CONCLUSION

The identified palynoassemblages from the crater lake sediments of the Neryunda sequence have an obvious mesophytic aspect and are accumulated in the iron-ore bearing pipe structures of the Tunguska paleovolcanic province (Obonitskaya, 1974). These palynoassemblages differ from those of the paleophytic type recovered from the pipe structures with volcanogenic deposits of the Kapaeva Formation located in the central Angara region (Naumov and Ankudimova, 1995), but they are comparable with the palynoassemblages from the upper part of volcanogenic deposits of the Putorana phytostratigraphic horizon located in the central part of the Tunguska basin (*Regional...*, 1981; Krugovykh, 1987). By a resolution of the Third Interdepartmental Stratigraphic Meeting of Central Siberia, this horizon was attributed to the Early Triassic and referred to the uppermost Induan–Olenekian Stage.

The composition of the Inogli palynoassemblage in the southeastern part of the Tunguska syneclise is of a mixed type; it is older than the Neryunda assemblage and younger than the paleophytic assemblages of the Kholok and Kochema formations in the upper reaches of the Nizhnyaya Tunguska (Ankudimova and Naumov, 1986). The sequence can probably be referred to the Dvurogii Horizon (Induan, Induan–Olenekian). Table 3 shows the correlation scheme of the respective units.

The age of the Putorana Horizon is still debatable. According to Sadovnikov (1981a, 1981b), this horizon was formed during a particular stage of fauna and flora evolution unknown in Europe, perhaps owing to a hiatus between the Tatarian Stage and the Vetluga Group. The Putorana Horizon belongs either to the lower Induan or to the Permian and corresponds to the aforementioned hiatus (Sadovnikov and Orlova, 1990).

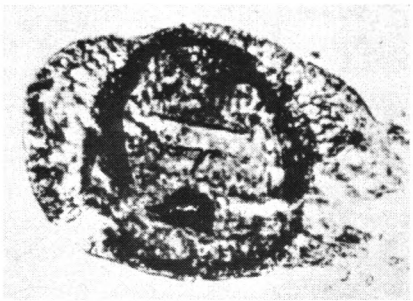
Goman'kov and Meyen (1986) are of the same point of view. The presence of certain plant genera in the volcanogenic bed of the Tunguska basin, for example, *Quadrocladus* and *Lueckisporites* pollen, observed in the interval between the upper part of the Bugarikta Formation and the upper part of the Yambukan Formation, suggests a correlation between this volcanogenic bed and the upper Tatarian Substage. It is possible, however, that a part of this volcanogenic bed corresponds to the hiatus between the Vyatka Horizon and the Vetluga Group of the Russian Platform. On the other hand, this assumption contradicts the ostracod fauna, which has a "mixed" Tatarian–Vetluga aspect in the volcanogenic beds and corresponds to the interval of the "Vyatka–Vetluga" hiatus.

Plate IV. Pollen from the deposits of the Neryunda sequence (magn. 600).

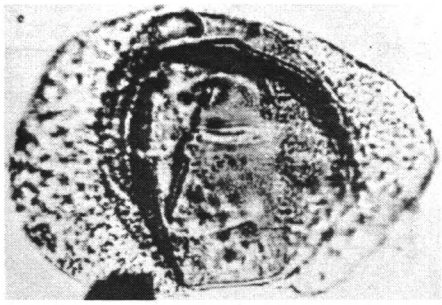
(1–3, 7, 8) *Taeniaesporites* sp.; (4–6) *Taeniaesporites noviaulensis* Leschik.; (9) *Striatohaploxypinus* sp.; (10) *Striatites*.

(1) Well 26, depth 37.6 m, Oktyabr'skii deposit; 2, 3, 6, 9) Well 46, depth of 128 m, Neryunda deposit; (4, 5, 7) Well 3, depth of 147 m, Kapaeva deposit; (8) Well 24, depth interval of 191–196 m, Kapaeva deposit; (10) Well 3, depth interval of 265–318 m, Kapaeva deposit.

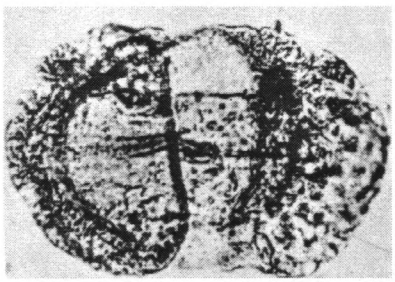
Plate IV



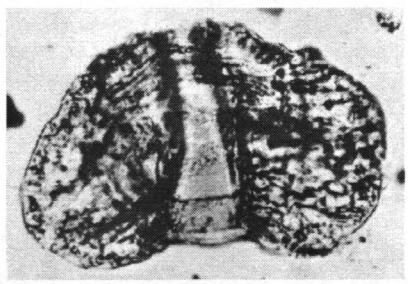
1



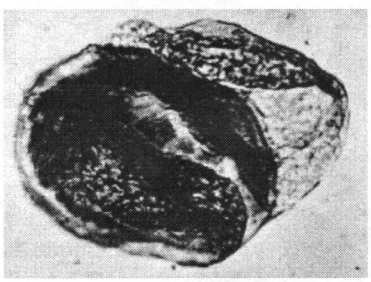
2



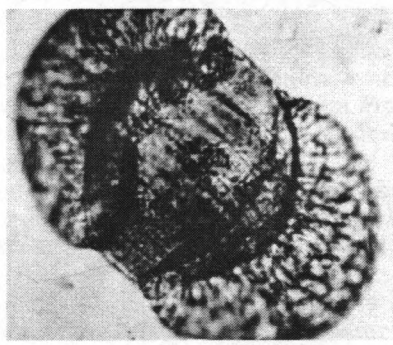
3



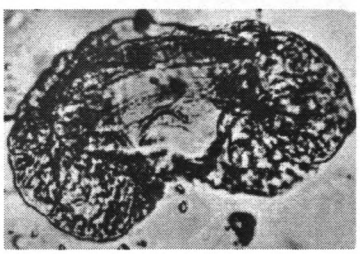
4



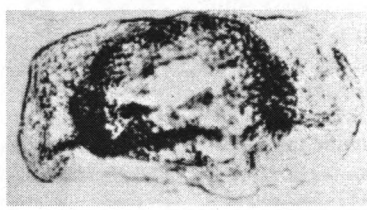
5



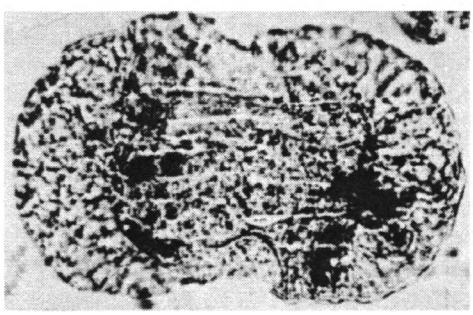
6



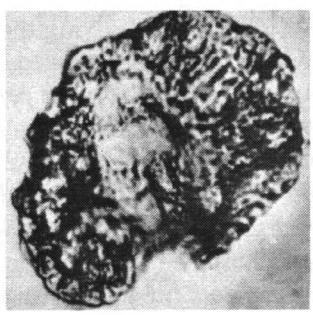
7



8



9



10

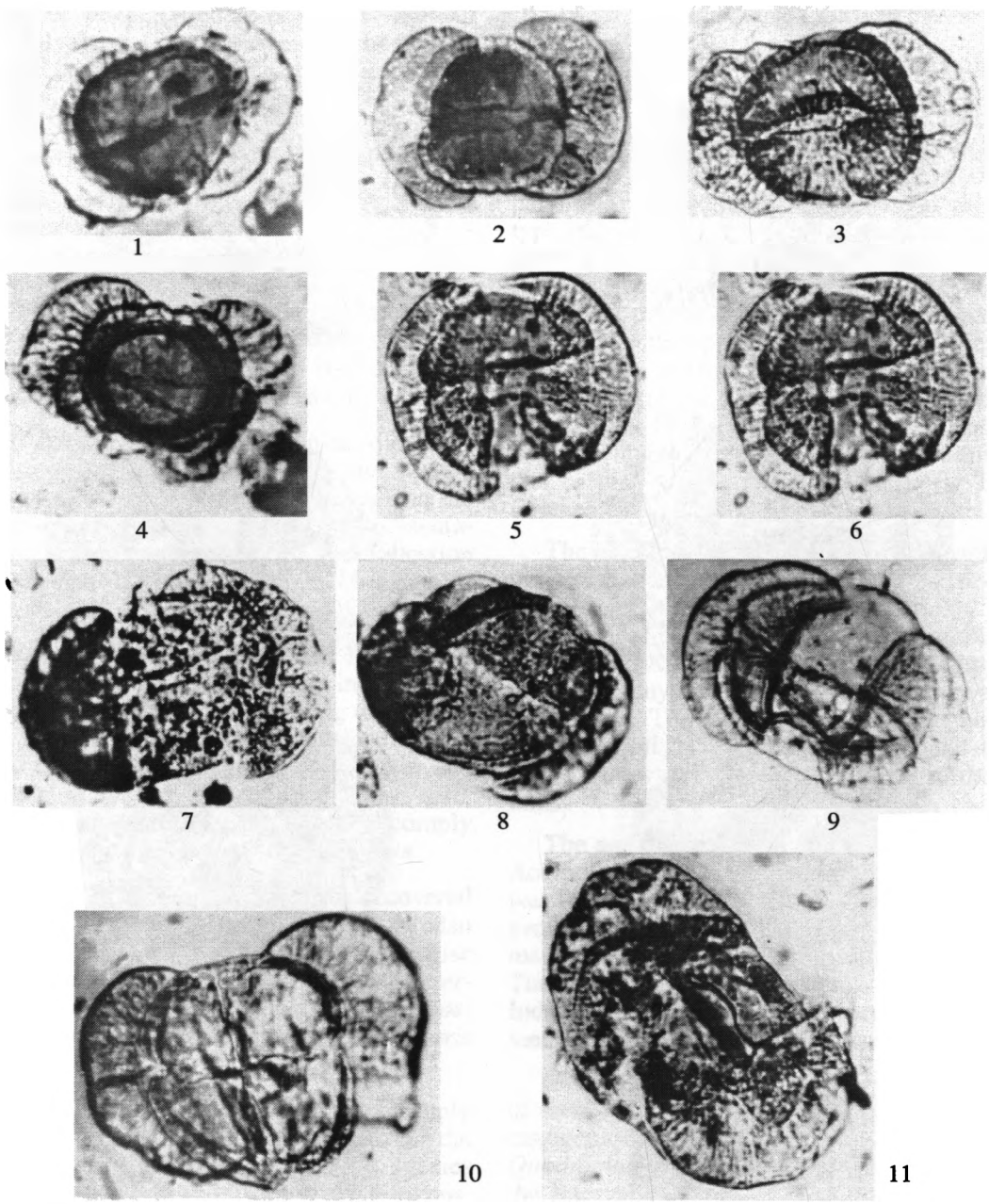


Plate V. Pollen from the deposits of the Neryunda sequence (magn. 600).
(1–4) *Lueckisporites virkkiae* Pot. et Klaus.; (5) *Lueckisporites tattoensis* Jans.; (6, 7) *Lueckisporites singhii* Balme.; (8–10) *Lueckisporites* spp.; (11) *Striatites*.
(1–11) Well 3, depth of 147 m, Kapaeva deposit.

Yaroshenko (1990), after studying the preparations of Obonitskaya's collection, has arrived at the conclusion that the presence of *Triquitrites proratus* spores and *Lueckisporites virkkiae* pollen is a characteristic feature of the palynoassemblage from the upper part of the Bugarikta Formation (the Putorana Group is composed of the upper part of the Bugarikta Formation and the Nidym, Kochechuma amd Yambukan Formations). And though the presence of the Triassic genus *Naumovaspora* contradicts this conclusion, Yaroshenko still maintains that "this is a younger (Djulfian or Dorashamian) stage of development of the Permian land flora" comprising forerunners of Triassic plants.

In total, the data given here testifies that the Neryunda deposits are Early Triassic in age, whereas the Ignnoli beds are presumably of the Early Triassic age. Pollen of *Gnetaceaepollenites, Lueckisporites* spp., *Taeniaesporites* sp., *Klausipollenites* sp., *Triadis-*

pora sp., and spores of *Naumovaspora striata* Jans., *Nevesisporites limatulus* Pl., *Cyathidites* sp., *Chomotriletes redunciformis* Korot., and *Kraeuselisporites* sp., serve as correlating taxa for the palynoassemblages of lacustrine deposits. These species, however, are either lacking or extremely scarce in the Upper Permian assemblages in the south of the Tunguska syneclise referred by Vakhrameev (1989) to the Tunguska floral province. In combination with faunal data, this can have but one interpretation: in Siberia, these plants could have appeared only in the Early Triassic.

The identified taxa allow us to correlate the crater lake deposits within the Angara and adjacent regions (the Angara and Nizhnyaya Tunguska basins), and also in their individual areas. Thus, palynoassemblages of the Neryunda Formation correlate with those of the Mal'tsevo Formation in the Kuznetsk basin (Romanovskaya, 1971; Obonitskaya, 1986) by the variety of coniferous *Triadispora* sp., and *Mirocachryidites* sp., associated with ribbed coniferous *Lueckisporites* spp. and *Taeniaesporites* spp., and also with pteridospermous *Vitreisporites* sp.and *Gnetaceaepollenites* sp., With palynoassemblages of the Bichura Formation in the Chelyabinsk basin (Tuzhikova, 1985); they are correlative by the presence of spores of *Nevesisporites* spp., *Osmundacidites* sp., and *Punctatisporites* sp., associated with striated pollen, and *Gnetaceaepollenites* sp.

The paleontological data on the analyzed deposits allows their correlation with the Kedrovaya Horizon of the Mal'tsevo Formation in the Kuznetsk basin, the Vetluga Group in the Russian Platform, the Baskunchak Group in the Moscow syneclise, and the Dnieper–Donets and Pericaspian depressions.

The results confirm the opinion (Krugovykh and Kiselev, 1982; Naumov *et al.*, 1988) that the pervasive volcanism and ore-forming processes in the Angara iron-ore region (except the Materikovyi ore deposit) came to an end in the pre-Neryunda period.

A specific peculiarity of palynoassemblages in the maar lacustrine sediments is the persistent presence of microphytoplankton represented by acritarchs inhabiting waters of normal (sea) salinity (Shakhmudes, 1973; Ivanovskaya *et al.*, 1974; Petros'yants, 1988). It is significant that acritarchs are lacking not only in volcaniclastic rocks of diatremers and synchronous tuffs abundant in the Korvuchana Group of the Tunguska syneclise (Yaroshenko, 1967, 1990; Obonitskaya, 1974; Mogucheva *et al.*, 1980; Ankudimova and Naumov, 1986; Naumov and Ankudimova, 1995), but also in tuffites and volcanogenic–sedimentary and tephroid rocks of the Early Triassic lakes of the Tunguska syneclise (Daragan-Sushchov, 1989). The tephrites contain spore–pollen assemblages, occasional plant imprints, and the remains of freshwater fauna. While setting aside the cause of water salinity of the maar lakes of the Tunguska paleovolcanic region, we should emphasize that the presence of acritarchs, apart from the palynological aspect of the spectra, is a reliable indicator of lacustrine deposits related to the ore-bearing pipe structures.

REFERENCES

Angaro-Vilyuiskii rudnyi poyas Sibirskoi platformy (The Angara–Vilyui Ore Belt of the Siberian Platform), Novosibirsk: Nauka, 1980.

Ankudimova, L.A. and Naumov, V.A., The Age and Correlation of Volcanogenic Deposits in the South of the Tunguska Syneclise, in *Problemy paleovulkanizma Sibirskoi platformy* (Problems of Paleovolcanism in the Siberian Platform), Irkutsk: Irkutsk. Gos. Univ., 1986, pp. 39–51.

Daragan-Sushchov, Yu.I., Regularities in the Development of the Early Triassic Lakes in the Tunguska Syneclise, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1989, no. 9, pp. 99–111.

Fon-der-Flaass, G.S., The Structure of the Neryunda and Kapaeva Magnetite Deposits, *Geol. Geofiz.*, 1977, no. 6, pp. 63–69.

Fon-der-Flaass, G.S., The Magmatic Stage in the Evolution of the Ore-Forming System of the Angara–Ilim Type, *Geol. Geofiz.*, 1992, no. 2, pp. 77–84.

Goman'kov, A.V. and Meyen, S.V., *Tatarinovaya flora (sostav i rasprostranenie v pozdnei permi Evrazii* (The Tatarina Flora: Composition and Occurrence Throughout Eurasia in the Late Permian), Moscow: Nauka, 1986.

Il'ina, T.I. and Gutova, L.N., Palynologic Characteristics of Triassic Deposits of the Neryunda Formation in the Angara–Kata Region, in *Novye metody analiza mineral'nogo syr'ya* (New Methods of Analysis of Mineral Products), Irkutsk: Vostochno-Sibirskaya Pravda, 1973, pp. 58–59.

Ivanovskaya, A.V., Kazanskii, Yu.P., and Timofeev, B.V., Distribution of Microfossils in Different Riphean Lithological–Facial Zones of East Siberia, in *Mikrofossilii SSSR* (Microfossils of the USSR), Novosibirsk: Nauka, 1974, pp. 89–102.

Krugovykh, V.V., Late Permian and Early Triassic Palynologic Assemblages of the Volcanogenic Sequence in the Middle Reaches of the Nizhnyaya Tunguska, *Geol. Geofiz.*, 1978, no. 10, pp. 146–150.

Krugovykh, V.V., On the Application of the Palynological Method for Subdivision and Correlation of the Permian–Triassic Volcanogenic Formations in the Tunguska Syneclise, in *Stratigrafiya i korrelyatsiya osadkov metodami palinologii* (Stratigraphy and Correlation of Sediments by Palynological Methods), Sverdlovsk: Ural. Nauchn. Tsentr Akad. Nauk SSSR, 1983, pp. 84–89.

Krugovykh, V.V., The Triassic Myospores from the Volcanogenic Deposits in the Tunguska Syneclise, in *Boreal'nyi trias* (The Boreal Triassic), Moscow: Nauka,1987, pp. 48–57.

Krugovykh, V.V. and Kiselev, R.V., Age and Structure of Magnetite "Bowl" Occurrences in the Kycheta Iron-Ore Deposit (Siberian Platform), *Geol. Geofiz.*, 1982, no. 5, pp. 115–119.

Kurbatova, A.A., Palynological Characteristic of the Early Triassic of Siberia, in *Materialy po palinologii Zapadnoi Sibiri* (The Materials on Palynology of West Siberia), Novosibirsk: Sib. Nauchno–Issled. Inst. Geol. Min. Syr., 1971, no. 117, pp. 16–20.

Mogucheva, N.K., Lebedev, V.M., Grigor'eva, K.N., *et al.*, On the Correlation of Triassic Volcanogenic Formations of

the Tunguska Syneclise, in *Paleontologiya i stratigrafiya triasa Srednei Sibiri* (The Triassic Paleontology and Stratigraphy of Central Siberia), Moscow: Nauka, 1980, pp. 86–92.

Naumov, V.A. and Ankudimova, L.A., Palynocomplexes and Age of Volcanogenic Deposits of the Angara–Kata Region (Middle Reaches of the Angara River), *Geol. Geofiz.*, 1995, vol. 36, no. 1, pp. 39–45.

Naumov, V.A., Ankudimova, L.A., and Penigina, V.L., Lacustrine Sediments of the Oktyabr'skii Iron-Ore Deposit, *Geol. Geofiz.*, 1988, no. 2, pp. 19–27.

Neustrueva, I.Yu., The Age of Volcanogenic Sedimentary Rocks at the Oktyabr'skii, Kapaeva, and Neryunda Iron-Ore Deposits in East Siberia as Indicated by Data on Ostracodes, in *Problema vozrasta geologicheskikh obrazovanii Vostochnoi Sibiri: itogi i dal'neishee napravlenie issledovanii s tsel'yu podgotovki k izdaniyu "Geolkarty-50"* (The Problem of the Age of Geologic Formations in East Siberia: Results and Further Research for the Preparation for Publication of "Geolkarta-50"), Irkutsk: Vostochno-Sibirskaya Pravda, 1984, pp. 62–63.

Obonitskaya, E.K., Correlation of the Lower Horizon of Volcanogenic Beds in the Northeastern and Central Parts of the Tunguska Syneclise Based on Palynological Data, in *Osnovnye voprosy palinologii permi i triasa SSSR* (Basic Problems of the Permian and Triassic Palynology of the USSR), Syktyvkar: Komi Fil. Akad. Nauk SSSR, 1973, pp. 41–42.

Obonitskaya, E.K., The Spore–Pollen Assemblages in Volcanogenic Deposits of the Central Part of the Tunguska Syneclise, in *Materialy po stratigrafii i paleogeografii Tungusskogo uglenosnogo basseina* (Materials on the Stratigraphy and Paleogeography of the Tunguska Coal Basin), Tomsk: Tomsk. Gos. Univ.,1974, pp. 160–165.

Odintsova, M.M., Ankudimova, L.A., and Faizulina, Z.Kh., The Role of Palynological Assemblages in the Development of Detailed Stratigraphic Subdivisions and Correlation of Sedimentary Formations, in *Problema vozrasta geologicheskikh obrazovanii yuga Vostochnoi Sibiri i puti ee resheniya s tsel'yu sozdaniya legend k gosudarstvennym geologicheskim kartam* (The Problem of the Age of Geological Formations in the South of East Siberia and the Means of Its Solution for Compilation of Legends to the State Geological Maps), Irkutsk: Vostochno-Sibirskaya Pravda, 1980, pp. 79–84.

Petros'yants, M.A., Reconstruction of Environments of Ancient Sedimentation, in *Palinologiya v SSSR* (Palynology in the USSR), Novosibirsk: Nauka, 1988, pp. 9–14.

Polyakova, E.N. and Vishnyakova, U.A., The Lower Triassic Lacustrine Deposits in the Territory of the Angara–Chuna Iron-Ore Region, in *Problema vozrasta geologicheskikh obrazovanii Vostochnoi Sibiri: itogi i dal'neishee napravlenie issledovanii s tsel'yu podgotovki k izdaniyu "Geolkarty-50"* (The Problem of the Age of Geologic Formations in East Siberia: Results and Further Research for the Preparation for Publication of "Geolkarta-50"), Irkutsk: Vostochno-Sibirskaya Pravda, 1984, pp. 63–64.

Pukhnarevich, M.M., Remarks on the Problem of Determination of the Upper Age Boundary of Iron-Ore Deposits in the Angara Province, in *Geologiya i poleznye iskopaemye Vostochnoi Sibiri* (The Geology and Useful Minerals of East Siberia), Irkutsk: Irkutsk. Gos. Univ., 1983, pp. 11–12.

Regional Stratigraphic Scheme of Correlated Triassic Deposits of the Tunguska Syneclise and Kuznetsk Basin, in *Resheniya 3-go Mezhvedomstvennogo regional'nogo stratigraficheskogo soveshchaniya po Mezozoyu i Kainozoyu Srednei Sibiri, g. Novosibirsk* (Resolutions of the Third Interdepartmental Regional Stratigraphic Meeting on Mesozoic and Cenozoic of Central Siberia, Novosibirsk), Novosibirsk: Nauka, 1981, pp. 20–25.

Rittmann, A., *Vulkane und ihre Taetigkeit*, Stuttgart: Ferdinand Enke, 1960.

Romanovskaya, G.M., Palynologic Characteristics of Triassic Deposits, in *Putevoditel' k polevomu marshrutu no. 2: Devonskie, kamennougol'nye, permskie, triasovye i yurskie otlozheniya. Ekskursiya po razrezam Kuzbassa 12–18 iyulya 1971 g. (III Mezhdunarodnaya palinologicheskaya konferentsiya)* (Guidebook to Field Excursion 2: The Devonian, Carboniferous, Permian, Triassic, and Jurassic Deposits, Third International Palynological Conference), Novosibirsk: Nauka, 1971, pp. 41–44.

Romanovskaya, G.M., Tabachnikova, I.P., and Dryagina, M.L., The Problem of the Permian–Triassic Boundary in Central Siberia from Palynologic Evidence, in *Palinologicheskii metod v stratigrafii* (The Palynological Approach in Stratigraphy), Leningrad: Vses. Geol. Inst., 1973, pp. 40–60.

Romanovskaya, G.M. and Vasil'eva, N.S., Palynostratigraphy of the Triassic Deposits, in *Prakticheskaya palinostratigrafiya* (Pratical Palynostratigraphy), Leningrad: Nedra, 1990, pp. 81–94.

Sadovnikov, G.N., Correlation and Age of Volcanogenic Formations in the Tunguska Basin, the Northern Reaches of the Anabar River, and Taimyr, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1981a, no. 9, pp. 49–63.

Sadovnikov, G.N., Regional Stratigraphic Upper Permian and Lower Triassic Units of the Siberian Platform and the Adjacent Areas, *Sov. Geol.*, 1981b, no. 6, pp. 74–84.

Sadovnikov, G.N. and Orlova, E.F., The Age of Continental Volcanogenic Deposits in the North of Central Siberia, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1990, no. 3, pp. 58–70.

Sadovnikov, G.N., Orlova, E.F., and Belozerov, V.P., Transition from the Permian to Triassic in the Continental Deposits of Taimyr and the Western Part of the Upper Reaches of the Yana River, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1981, no. 5, pp. 53–64.

Shakhmudes, V.A., Microphytoplankton as an Indicator of the Facial Affinity of Sediments, in *Mikrofossilii drevneishikh otlozhenii* (The Microfossils of the Most Ancient Deposits), Moscow: Nauka, 1973, pp. 50–57.

Strakhov, L.G., The Oktyabr'skii Ore Deposit, in *Angaro-Ilimskie zhelezorudnye mestorozhdeniya* (The Angara–Ilim Iron-Ore Deposits), Moscow: Gosgeoltekhizdat, 1960, pp. 229–235.

Strakhov, L.G., *Rudonosnye vulkanicheskie apparaty yuga Sibirskoi platformy* (Ore-Bearing Volcanogenic Structures in the South of the Siberian Platform), Novosibirsk: Nauka, 1978.

Tuzhikova, V.I., *Miospory i stratigrafiya opornykh razrezov triasa Urala. Nizhnii trias, pogranichnaya verkhnyaya perm'* (The Myospores in the Triassic Stratigraphic Reference Sections of the Urals: The Lower Triassic; the Boundary Beds of the Upper Permian), Sverdlovsk: Ural. Nauchn. Tsentr Akad. Nauk SSSR, 1985.

Vakhrameev, V.A., *Problemy stratigrafii mezozoya: Izbrannye trudy* (The Problems of the Mesozoic Stratigraphy: Selected Works), Moscow: Nauka, 1989.

Varyukhina, L.M., *Spory i pyl'tsa krasnotsvetnykh i uglenosnykh otlozhenii permi i triasa severo-vostoka evropeiskoi chasti SSSR* (Spores and Pollen from the Permian and Triassic Red Rocks and Carboniferous Deposits in the Northeast of the European Part of the USSR), Leningrad: Nauka, 1971.

Yaroshenko, O.P., The Spore–Pollen Assemblages and the Age of Tuffogenic Deposits in the Tunguska Basin, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1967, no. 3, pp. 117–125.

Yaroshenko, O.P., The Assemblages of Myospores and the Age of Tuffogenic–Sedimentary Rocks in the Tunguska Basin, *Paleofloristika i stratigrafiya fanerozoya* (The Phanerozoic Paleoflora and Stratigraphy), Moscow: Geol. Inst. Akad. Nauk SSSR, 1990, no. 2, pp. 44–84.

Stratigraphy and Geological Correlation, Vol. 5, No. 4, 1997, pp. 334–341. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 4, 1997, pp. 27–34.
Original Russian Text Copyright © 1997 by Kasintsova, Olfer'ev.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

The Paramonovo Formation of the Albian in the European Part of Russia and Its Age as Indicated by Microfauna

L. I. Kasintsova* and A. G. Olfer'ev**

**All-Russia Research Institute of Geology, Srednii pr. 74, St. Petersburg, 199026 Russia*
***Geological Company "Geosintez" (PGO "Tsentrgeologiya"), Varshavskoe sh. 39a, Moscow, 113105 Russia*

Received March 20, 1995; in final form, May 15, 1996

Abstract—The history of the recognition and stratigraphic investigation of the Paramonovo Formation, which is related to the discovery of the Cretaceous System in the Russian platform, is described. Detailed characteristics of the formation are supplemented with data on mollusks occasionally occurring in the unit and on its foraminiferal assemblages with their age interpretation. Coexisting radiolarians are also described in detail and referred to the *Porodiscus kavilkinensis–Crolanium cuneatum* assemblage, whose distribution over the Russian platform is considered and correlated with coeval faunas in other regions. The data obtained are used to substantiate the late Albian age of the Paramonovo Formation.

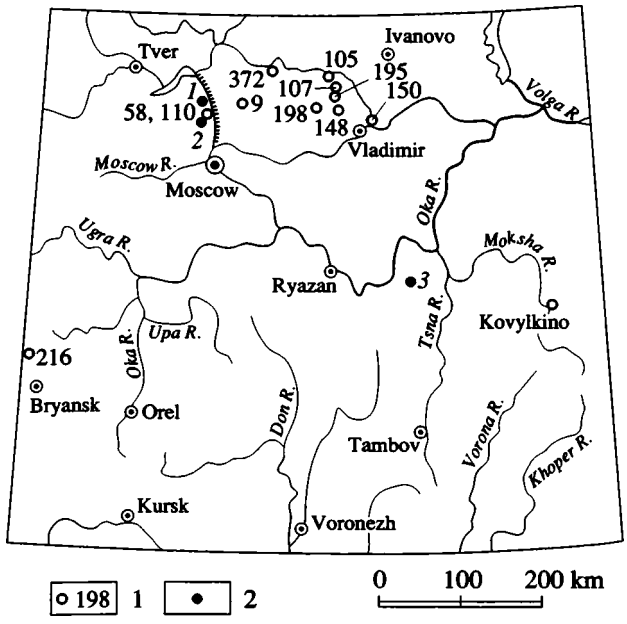
Key words: *Russian platform, Paramonovo Formation, Albian Stage, foraminifers, radiolarians, assemblage, association, age*

Deposits of the Paramonovo Formation are widespread in the Russian platform. They represent an upper part of the Albian Stage. C. Rouiller was the first to describe the Albian strata in 1847, when he discovered an outcrop of green sands and sandstones with new ammonite species (*Ammonites engersi* Rouill. and *A. talitzianus* Rouill.) and remains of ichthyosaur, fishes, and fossil wood near the Engers Factory of the village of Nikol'skoe at the Talitsa River (at present the Sergiev Posad district of the Moscow region). In the same year, an amateur geologist, V. Katala, discovered ammonites from the Zolotaya Gora locality between the villages of Kovshino and Stepanovo of the Yakhroma district and suggested that one of them is identical to *Ammonites talitzianus* Rouill., whereas two others (later identified as *Hoplites dentatus* Sow.) were reported as unknown before in the Moscow region. Earlier, Auerbach and Frears (1846) demonstrated that these ammonites are characteristic of the Lower Cretaceous in Western Europe, and the aforementioned finds proved coeval deposits to be present in Russia. A while later, in 1872, G.A. Trautschold discovered new sections enclosing Albian ammonites near the village of Paramonovo at the Volgusha River and near the villages of Berezniki and Chekmovo at the Talitsa River. His collection of fauna was comprehensively studied by Nikitin (1888), who correlated the fauna-bearing beds with the Gault of the Anglo-Parisian basin. Then in 1896, V.D. Sokolov detected that the sands with fauna are overlain by dark gray clayey beds afterward designated as the Paramonovo Clay (Dan'shin, 1947). The beds were also included into the Gault of Russia. In 1922, S.A. Dobrov referred the sands with ammonites and the overlying Paramonovo Clay to the Middle and Upper Gault, respectively. Further, in 1932, this scientist established that at the base of the Paramonovo Clay there is a unit of sandy and clayey beds with phosphorite concretions and pebbles, which differ from the green sands of the Middle Gault.

In 1986, the upper clay unit was given the status of the Paramonovo Formation (Olfer'ev, 1986). Olfer'ev established that this unit is stratigraphically discordant with respect to underlying deposits and characterizes a complete sedimentation cycle of a three-member structure.

The lower part of the cycle includes a series of elementary rhythms, which are 0.5–1.2 m thick and display a transgressive trend of sedimentation. Inside a rhythm, the basal fine-grained sand grades upward into silt and clay, and the thickness of separate layers varies from 0.1 to 0.5 m. The structure of a rhythm depends on its stratigraphic position in this part of the section. Sandy beds with quartz gravel, pebbles, and concretions of black phosphorite at the base predominate in the basal rhythms, where clay interlayers are random. In the middle part of the unit, clayey layers become more frequent, whereas sandy and silty beds are equally abundant. Upwards of the section, sandy layers gradually disappear from the structure of the rhythms, and clay turns into their main component. The total thickness of this part of the cycle is usually less than 6 m.

The middle part of the Paramonovo Formation corresponds to the maximum of the Albian transgression and consists of dark gray, irregularly micaceous silty clays with abundant glauconite and mud-eater tracks filled with light colored silt. Clay here composes beds



Geographic localities of studied sections: (1) well and its number; (2) natural exposures near villages of Paramonovo (*1*), Spas-Kamenka (*2*), and Shigaevo (*3*).

4–5 m thick and separated by thin (0.5–0.8 m) layers of clayey silt displaying the characteristic roiling structure and locally intense bioturbation. Upwards of the section, the thickness and frequency of silty layers steadily grow. This part of the formation is up to 20 m thick.

The upper part of the Paramonovo cycle corresponds to the regressive phase of the late Albian Sea and consists of clayey fine-grained glauconite–quartz sands. The grain size of sandy particles increases upward the section. This part of the Paramonovo Formation is up to 25 m in thickness.

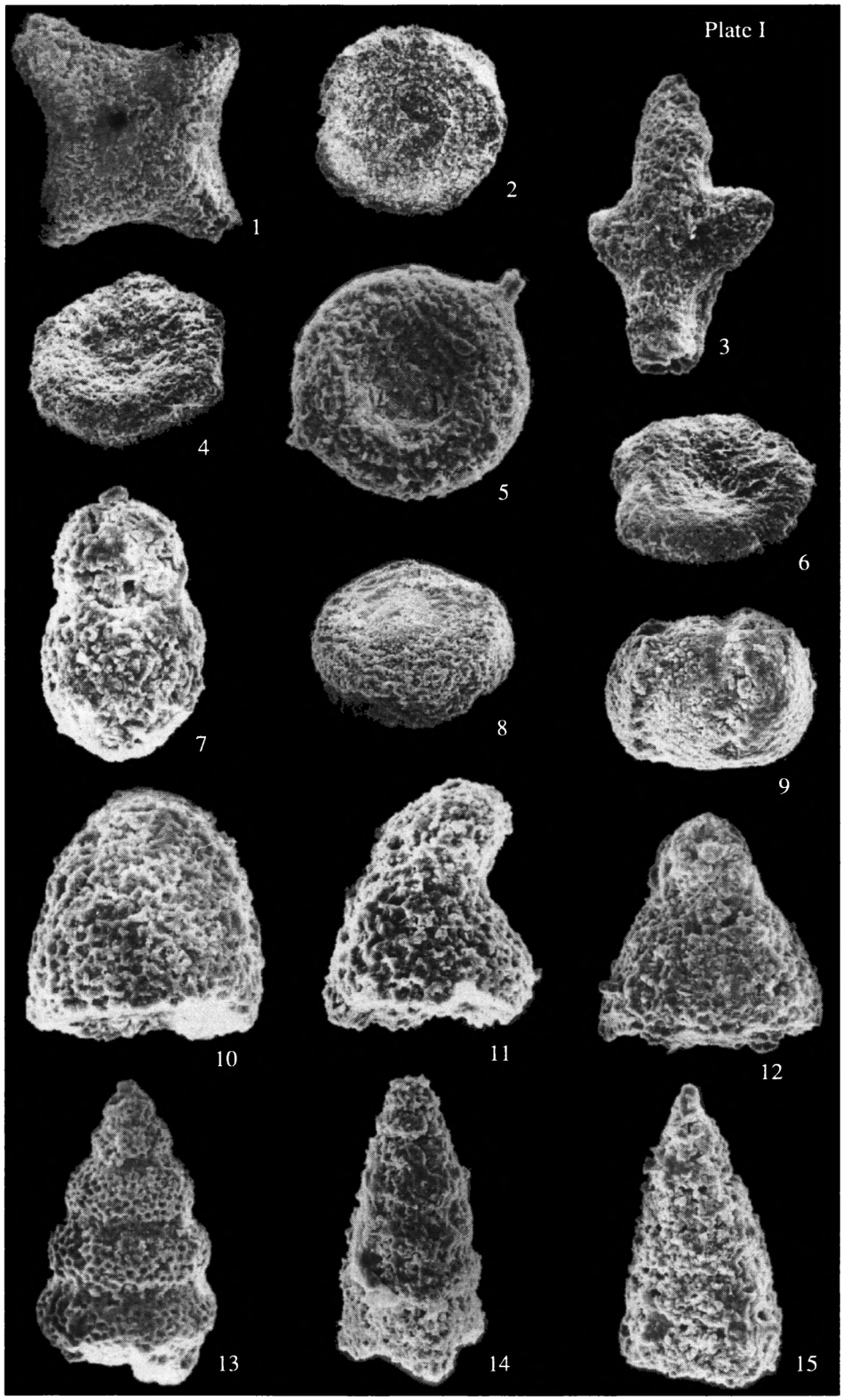
After the work of Sokolov, the status of the Paramonovo Formation stratotype was attributed to the section near the village of Paramonovo at the Volgusha River, where recurrent landslides regularly expose the lower part of the sedimentary cycle. The middle part of the cycle is recovered by wells located nearby (wells 110 near Paramonovo and 58 near Gavrilkovo). However, its upper portion in this area is eliminated by exaration. To avoid confusion, it was suggested to choose as the hypostratotype the depth interval of 62.0–94.7 m in Well 9 near the village of Vorokhobino, located 12 km to the west of Sergiev Posad (Zagorsk), where the formation is recovered in its whole stratigraphic range characterized by fossils.

The Paramonovo Formation is widespread in the Moscow syneclise and northern Voronezh anteclise, where it underlies Upper Cretaceous strata. In the Ul'yanovsk–Saratov depression, similar clayey beds are included in the Knyazhukhino sequence by G.V. Zhukova and in the Kremenki lithostratigraphic unit by E.L. Pisannikova. The same beds are also known as the Pimbur sequence within the area of the Tokmovo uplift (*Unifitsirovannye...*, 1993).

There were many attempts to evaluate the age of the Paramonovo Formation. Correlating the Paramonovo beds with the Upper Gault of the Anglo-Parisian basin, Dobrov referred them to the upper Albian, although the former and latter units are inadequate in their stratigraphic ranges. Macrofossils are not abundant in the formation. In its uppermost beds, penetrated by Well 372 near the village of Koshelevo, the Pereslav district of the Yaroslavl region, P.A. Gerasimov (*Geologiya SSSR*, 1971) discovered an ammonite cast and classified it as a form of the genus *Hoplites*. In the opinion of E.Yu. Baraboshkin (personal communication), this form resembles the middle Albian species *Mojsisovicsia subdelaruei* (Spath), yet this conclusion conflicts with Gerasimov's data that basal beds of the formation (Well 158 near the village of Kisarovo, the Suzdal district of the Vladimir oblast) enclose inoceram *Actinoceramus* cf. *sulcatoides* Sav. of the late Albian age. In addition, Dobrov discovered the late Albian ammonites *Pervinqueria* cf. *inflata* (Sow.), *Callihoplites vraconensis* (Pict. et Camp.), and *Prohysteroceras* aff. *halli* Sow. from basal Paramonovo strata near the village of Shigaevo, the Putyatino district of the Ryazan region.

Foraminifers represent the more frequently occurring fossils of the Paramonovo Formation. Their first species, such as *Ammobaculites agglutinans* (Orb.), *Gaudryinella albica* Aleks., *Haplophragmium aequalis* (Roem.), *Haplophragmoides nonioninoides* (Reuss), *Reophax* aff. *scorpiurus* Mont., and *Tristix excavata* (Reuss), were identified in 1964 by Aliev and Smirnova (1969) in the Vladimir oblast (wells 148, 150, and 198 near villages of Fedorovskoe, Churilovo, and Borisovo, respectively) (figure). In all three localities, foraminifers coexist with radiolarians. Examining later the Paramonovo Clay in the stratotype area (Well 58 near Paramonovo and Well 9 near Vorokhobino), Olfer'ev (1986) and N.A. Chernyshova (unpublished data) discovered here agglutinated benthonic and calcareous planktonic foraminifers: *Verneuilinoides borealis* Tappan var. *assonoviensis* Zasp., *Gaudryina gradata* (Berth.), *G. neocomiana* Chal., *Trochammina numerosa* Loso, *T. neocomiana* Mjatl., *T.* cf. *subbotinae* Zasp., *Crithionina dubia* Bulat., *Gyroidina oblonga* Zasp., *Ammobaculites aequalis* (Roem.), *Hedbergella infracretacea* (Glaessn.), and *Guembelitria cenomana* (Keller). Smirnova and Chernyshova (unpublished data) interpreted this assemblage as the late Albian in age without any comment.

The most diverse foraminiferal community was revealed by T.N. Gorbachik in the Spas-Kamenka quarry, 11 km away to the south from the village of Paramonovo. According to Alekseev (1991), the community is confined to the middle part of the Paramonovo Formation and mainly consists of agglutinated foraminifers, although some beds also yielded secretory benthonic and planktonic species. In the vertical



sequence, there are three assemblages of different taxonomic composition. The oldest Assemblage I includes only agglutinated species: *Ammobaculites variabilis* Tappan, *A. cuyleri* Tappan, *A. goodlandensis* Cush., *Reophax deckeri* Tappan, *Lagenammina distributa* Mjatl., and *Haplophragmoides concavus* (Chapm.). Only two initial species of the list are restricted in distribution by the upper Albian, whereas others occur in

various Albian horizons of North America. According to Gorbachik, this assemblage apparently is of the late Albian age.

Assemblage II represents a combination of agglutinated and secretory foraminifers. Species of the first type are *Haplophragmoides* cf. *rosaceus* Subb., *Reophax* aff. *scorpiurus* Brady, *Ammobaculites subcretaceus* Cush. et Alexan., *Textularia chapmani* Lalick., *Trochammina umiatensis* Tapp., *T. kugitangensis* N. Byk., *T.* cf. *bulloides* Tair., *Dorothia levis* Jann., and *Gaudryina filiformis* (Berth.). Secretory benthonic forms include *Frondicularia gaultina* Reuss, *Nodosaria doliiformis* Eich., *N. paupetcula* Reuss, *Lenticulina gaultina* (Berth.), *Saracenaria cushmani* Tapp., *Marginulinopsis acuticostata* (Reuss), *M.* ex gr. *gracilissima* (Reuss), *Dentalina inconstans* Jann., *D. debilis* (Berth.), *D. sororia* Reuss, *Marginulina costalata* (Chapm.), *M. jonesi* (Reuss), *M. pseudolinearis acuticostata* (Reuss), *Gavelinella cenomanica* (Brotz.), *Lingulogavelinella* cf. *stellata* Buk., and *L. globosa* (Brotz.). Secretory planktonic species are *Hedbergella infracretacea* (Glaessn.), *H. delrioensis* (Cars.), and *Ticinella digitalis* Sigal. Gorbachik granted the late Albian age of the assemblage to be beyond doubt and suggested that it corresponds to the *Stoliczkaia dispar* Zone of the terminal Albian (Vraconian).

Assemblage III includes almost all agglutinated species of the previous assemblage, excluding *Dorothia levis* Jann., *Textularia chapmani* Lalick., and *Haplophragmoides* cf. *rosaceus* Subb. Gorbachik also considered this assemblage as the late Albian in age, but did not exclude the possibility of referring it to the Cenomanian.

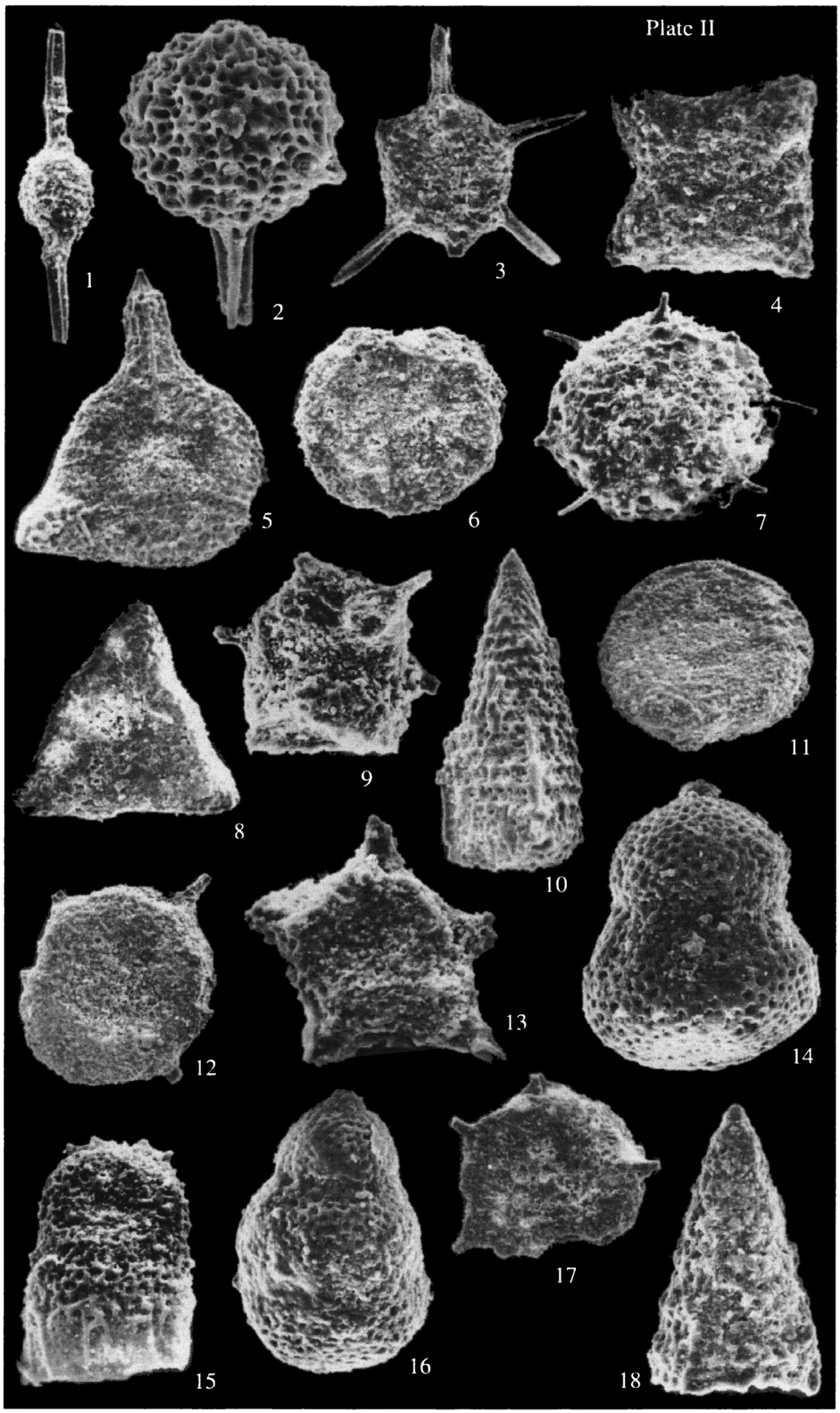
Radiolarians, often coexisting with foraminifers, are likewise significant age markers of the Paramonovo Formation. Aliev and Smirnova (1969) were the first to describe radiolarians from wells 148, 150, and 198 penetrating though the Paramonovo Clay in the central Vladimir oblast. A similar radiolarian assemblage was later recovered from Well 216 in the Bryansk oblast. In general, these assemblages include more than 10 species, the most characteristic among which are *Porodiscus kavilkinensis* Aliev, *P. inflatus* Smirnova et Aliev, *Theocampe cylindrica* Smirnova et Aliev, *Dictyomitra ferosia* Aliev, and *Crolanium cuneatum* (Smirnova et Aliev). According to these authors, some of the distinguished species are similar to those from the middle Volga region. Many of the spumellarians of the assemblage can be identified only at the generic level due to a poor degree of preservation. They are rather abundant and include thin and thicker flat shells of the genus *Porodiscus*, yet nassellarians, especially those of *Dictyomitra* and *Crolanium* genera (originally referred to the genus *Siphocampe*) are the dominant forms of the assemblage. The *Dictyomitra* shells are ornamented with small round pores, whereas the *Crolanium* forms are triangular in the distal cross section of their skeletons. For the sake of convenience, we termed this group of fossils the *Porodiscus kavilkinensis–Crolanium cuneatum* assemblage.

Kazintsova distinguished an analogous radiolarian assemblage in the sample collection of Olfer'ev from the Paramonovo Formation hypostratotype in the Moscow syneclise (depth interval of 62.0–94.7 m in Well 9 near the village of Vorokhobino, Sergiev Posad district of the Moscow oblast). Samples 31–39 from the depth interval of 70.0–88.5 m yielded here the following species: *Porodiscus inflatus* Smirnova et Aliev, *P. kavilkinensis* Aliev, *Orbiculiforma multa* (Kozlova), *O. multangula* Pessagno, *O.* cf. *railensis* Pessagno, *O. nevadaensis* Pessagno, *Crucella aster* (Lipman), *C. crux* (Lipman), *Cromyodruppa concentrica* Lipman, *Cyrtocalpis eurystoma* Rust, *Dictyomitra ferosia* Aliev, *Crolanium cuneatum* (Smirnova et Aliev), *Cr. triangulare* (Aliev), and some other forms. One more assemblage of *Porodiscus kavilkinensis* Aliev, *P. inflatus* Smirnova et Aliev, *Cromyodruppa concentrica* Lipman, *Diacanthocapsa euganea* (Squinabol), *Theocampe simplex* Smirnova et Aliev, and *Dictyomitra ferosia* Aliev is known from Well 105 near the village of Ivorovo (depth interval of 59.0–89.0 m, samples 340–347). Species from Well 107, near the village of Belyanitsino, (depth interval of 22.0–32.0 m, samples 351–353) are represented by *Porodiscus kavilkinensis* Aliev, *P. inflatus* Smirnova et Aliev, *Diacanthocapsa euganea* (Squinabol), *Theocampe simplex* Smirnova et Aliev, *Dictyomitra ferosia* Aliev, and *Crolanium cuneatum* Smirnova et Aliev. In addition, Well 195 near the village of Turab'evo (depth interval of 49.5–71.0 m, samples 446–450) yielded *Porodiscus kavilkinensis* Aliev, *P. inflatus* Smirnova et Aliev, *Theocampe cylindrica* Smirnova et Aliev, *Dictyomitra ferosia* Aliev, and other forms.

Finally, G.E. Kozlova kindly provided us with samples bearing radiolarians from the upper Albian deposits of the Kovylkino Locality in the Penza region, which were collected by scientists of the All-Union Research

Plate I. Albian radiolarians from the Moscow syneclise: (1) *Crucella aster* (Lipman), ×145; (2) *Porodiscus kavilkinensis* Aliev, ×110; (3) *Crucella crux* (Lipman), ×125; (4) *Orbiculiforma multangula* Pessagno, ×110; (5) *Orbiculiforma* cf. *railensis* Pessagno, ×180; (6) *Orbiculiforma nevadaensis* Pessagno, ×110; (7) *Diacanthocapsa euganea* (Squinabol), ×215; (8) *Porodiscus inflatus* Smirnova et Aliev, ×160; (9) *Cromyodruppa concentrica* Lipman, ×180; (10) *Cyrtocalpis eurystoma* Rust, ×205; (11) *Cyrtocalpis* ? sp., ×200; (12) *Dictyocephalus* sp., ×145; (13) *Dictyomitra ferosia* Aliev, ×180; (14) *Crolanium cuneatum* (Smirnova et Aliev), ×145; (15) *Crolanium triangulare* (Aliev), ×160.

Localities: (1, 3–6, and 9–15) from Well 9 near the village of Vorokhobino; (2 and 8) from Well 105 near the village of Ivorovo; (7) from Well 107 near the village of Belyanitsino, all in the Moscow syneclise of the Russian platform. Materials are stored at the All-Russian Research Institute of Geology, Laboratory of Microfauna, Collection no. 685.



Institute of Prospecting Geology southwest of Saransk. These radiolarians are better preserved and more diverse than in the Vladimir oblast. We identified more than 20 species among them: *Porodiscus kavilkinensis* Aliev, *P. inflatus* Smirnova et Aliev, *Pentinastrum subbotinae* Lipman, *Praeconocaryomma lipmanae* Pessagno, *Stylotrochus hexacanthus* Lipman, *Orbiculiforma nevadaensis* Pessagno, *O. quadrata* Pessagno, *O.* cf.

railensis Pessagno, *Crucella aster* Lipman, *Archaeospongoprunum carrierensis* Pessagno, *Ar. praelongum* Pessagno, *Theocampe simplex* Smirnova et Aliev, *T. cylindrica* Smirnova et Aliev, *Dictyomitra ferosia* Aliev, *Crolanium cuneatum* (Smirnova et Aliev), *Cr. triangulare* (Aliev), *Cr. triquetrum* Pessagno, and others. In addition to the forms described by Smirnova and Aliev, this assemblage includes species known from Upper Cretaceous deposits of the Kuznetsk region (Lipman, 1952). The latter are represented by discoid tetra- to hexagonal skeletons armored with spines (genera *Crucella, Pentinastrum*, and *Stylotrochus*). Besides these, we distinguished the Albian–Cenomanian taxa known from California (Pessagno, 1976, 1977), such as spherical tuberculate spumellarians (genus *Praeconocaryomma*), discoid cancellate forms (genus *Orbiculiforma*), species with two polar spines (genus *Archaeospongoprunum*), and nassellarians (genus *Crolanium*).

Albian radiolarians from the Moscow syneclise and Tokmovo uplift of the Volga–Ural anteclise (the Kovylkino locality) are studied for the first time and photographed under a scanning microscope (see Plates I and II).

Comparing the *Porodiscus kavilkinensis–Crolanium cuneatum* assemblage of the Russian platform with coeval assemblages from other regions, we noted a certain similarity between them. First of all, this concerns assemblages from the Greater Caucasus where, according to Aliev (1965, 1968, 1976), Azizbekova and Abbasov (1990), Abbasov (1993), and our data (Kazintsova, 1990), clays of the *Aucellina* Horizon contain over 40 radiolarian species referred to the *Dictyomitra disparlita–Crolanium triangulare* assemblage. The late Albian age of this assemblage is substantiated by the coexisting foraminifers of the *Hedbergella infracretacea* Zone and by belemnites of the *Parahibolites pseudoduvalia* Zone. Common radiolarian species in the assemblages under comparison are *Cenosphaera originala* Aliev, *C. adornata* Aliev, *Conosphaera haeckeli* Aliev, *Porodiscus kavilkinensis* Aliev, *P. inflatus* Smirnova et Aliev, *Diacanthocapsa euganea* (Squinabol), *Sethocyrtis mosquensis* Smirnova et Aliev, *Theocampe simplex* Smirnova et Aliev, *T. cylindrica* Smirnova et Aliev, *Dictyomitra tekschaensis* Aliev, *D. disparlita* Aliev, *D. ferosia* Aliev, *Lithocampe chalilovi* Aliev, *Crolanium cuneatum* (Smirnova et Aliev), and *C. triangulare* (Aliev).

Several species of the assemblage in question, such as *Pentinastrum subbotinae* Lipman, *Crucella aster* (Lipman), *C. crux* (Lipman), *Orbiculiforma multangula* Pessagno, *O. nevadaensis* Pessagno, *Crolanium cuneatum* (Smirnova et Aliev), and *Cr. triangulare* (Aliev), are also known from the upper Albian deposits of Crimea (Kazintsova, 1990), where their skeletons coexist with fossil planktonic foraminifers *Hedbergella portsdownensis* (Williamis-Mitchell), *Globigerinella ultramicra* Subb., *G. aissana* Sigal, *Rotalipora appenninica* (Renz), and *Guembelina cenomanica* Agal. (Drushchits and Gorbachik, 1959; *Putevoditel'...*, 1971). In addition to foraminifers, the late Albian age of deposits bearing radiolarians is supported by the discovery of belemnite rostrums of *Neohibolites stylioides* Renng., *N. subtilis* Krimh., and *Parahibolites pseudoduvalis* Sinz., and by bivalves *Aucellina gryphaeoides* Sow., *Inoceramus concentricus* Park., *I. sulcatus* Park., and *I. anglicus* Woods.

Some representatives of radiolarians from the Russian platform exist as well in assemblages of Sakhalin, whose late Albian age is determined on the basis of ammonite and inoceram fauna (*Atlas...*, 1993). This group of radiolarians includes *Praeconocaryomma lipmanae* Pessagno, *Porodiscus kavilkinensis* Aliev, *P. inflatus* Smirnova et Aliev, *Archaeospongoprunum praelongum* Pessagno, *Ar. carrierensis* Pessagno, *Theocampe cylindrica* Smirnova et Aliev, *Crolanium cuneatum* (Smirnova et Aliev), *Cr. triangulare* Aliev, and *Cr. triquetrum* Pessagno.

Thus, different groups of fossils, such as foraminifers in the Russian platform, foraminifer–bivalve–belemnite associations in the Caucasus and Crimea, ammonites and inocerams in the Sakhalin, or foraminifers and ammonites in California, provide a reliable basis to infer the late Albian age of coexisting radiolarian assemblages, whose synchronism is also evident from many species in common.

The *Porodiscus kavilkinensis–Crolanium cuneatum* assemblage identified in the Russian platform (Vladimir, Moscow, and Penza oblast) is not very diverse (table). It includes 30 species in total, 18 of which are represented by spumellarians of ten genera with dominant discoid and cancellate forms. Nassellarians consist of 12 species of 7 genera and are of a smaller size. All radiolarians are recovered from clays. Their morphology and ecological features allow us to suggest that the Albian Sea in the Russian platform was relatively shallow. This is evident from the discoid shape of spongodiscids and porodiscids, which had rather large and thick cancellate shells indicating fairly

Plate II. Albian radiolarians from the Tokmovo uplift: (1) *Archaeospongoprunum praelongum* Pessagno, ×105; (2) *Praeconocaryomma lipmanae* Pessagno, ×250; (3) *Stylotrochus hexacanthus* Lipman, ×105; (4) *Crucella aster* (Lipman), ×180; (5) *Paronaella* (?) sp. 2 (Pessagno, 1973), ×105; (6) *Orbiculiforma nevadaensis* Pessagno, ×105; (7) *Stylotrochus* ? sp., ×105; (8) *Patulibracchium*? sp., ×105; (9) *Pentinastrum*? sp., ×180; (10) *Crolanium triquetrum* Pessagno, ×145; (11) *Porodiscus inflatus* Smirnova et Aliev, ×145; (12) *Orbiculiforma quadrata* Pessagno, ×105; (13) *Pentinastrum subbotinae* Lipman, ×215; (14) *Theocampe simplex* Smirnova et Aliev, ×250; (15) *Mitrocalpis*? sp., ×160; (16) *Dictyomitra ferosia* Aliev, ×215; (17) *Orbiculiforma* cf. *railensis* Pessagno, ×105; (18) *Crolanium triangulare* (Aliev), ×160.

Locality: Russian platform southwestward of Saransk near the village of Kovylkino. Materials are stored at the All-Russian Research Institute of Geology, the Laboratory of Microfauna, Collection no. 769.

Distribution of radiolarian species of the *Porodiscus kavilkinensis–Crolanium cuneatum* assemblage in the Russian platform, Crimea, and Greater Caucasus

Species of radiolarians	Russian platform			Crimea, Mar'ino locality	Greater Caucasus, Konakhkend locality
	Moscow syneclise		Volga–Urals anteclise		
	Wells 148, 150, 198	Wells 9, 105, 107, 195	Well near Kovylkino		
Cenosphaera adornata Aliev	+		+		+
C. orginala Aliev	+				+
Conosphaera haeckeli Aliev	+		+		+
Praeconocaryomma lipmanae Pessagno			+		
Porodiscus kavilkinensis Aliev	+	+	+		+
P. inflatus Smirnova et Aliev	+	+	+		+
Pentinastrum subbotinae Lipman			+	+	
Stylotrochus hexacanthus Lipman			+		
Cromyodruppa concentrica Lipman		+			
Orbiculiforma multa (Kozlova)		+			
Or. nevadaensis Pessagno		+	+	+	
Or. quadrata Pessagno			+		
Or. railensis Pessagno		+	+		
Or. multangula Pessagno		+		+	+
Crucella aster (Lipman)		+	+	+	
C. crux (Lipman)		+		+	
Archaeospongoprunum praelongum Pessagno			+		
Ar. carrierensis Pessagno			+		
Cyrtocalpis eurystoma Rust		+		+	
Sethocyrtis mosquensis Smirnova et Aliev	+		+		+
Diacanthocapsa euganea Squinabel		+			+
Theocampe symplex Smirnova et Aliev	+	+	+		+
Th. cylindrica Smirnova et Aliev	+	+	+		+
Dictyomitra ferosia Aliev	+	+	+		+
D. tekschaensis Aliev	+		+		+
D. disparlita Aliev			+		+
Lithocampe chalilovi Aliev			+		+
Crolanium triangulare (Aliev)		+	+	+	+
Cr. cuneatum (Smirnova et Aliev)	+	+	+	+	+
Cr. triquetrum Pessagno			+		

cool environments in the sea basin. The presence of identical species in coeval assemblages from the Russian platform, Crimea, and Caucasus shows that Boreal and Tethyan seas were well interrelated.

Thus, our results on foraminifers and radiolarians from the Paramonovo Formation do not contradict one another and prove the late Albian age of the unit.

REFERENCES

Abbasov, A.B., Cretaceous Radiolarians from Azerbaijan (Biostratigraphy, Evolution, and Paleoecology), *Doctoral (Geol.–Mineral.) Dissertation*, Baku: Inst. of Geology, Academy of Sciences of Azerbaijan, 1993.

Aliev, Kh.Sh., *Radiolyarii nizhnemelovykh otlozhenii Severo-Vostochnogo Azerbaidzhana i ikh stratigraficheskoe znachenie* (Radiolarians from the Lower Cretaceous Deposits in the Northeastern Azerbaijan and Their Stratigraphic Significance), Baku: Akad. Nauk Azerb. SSR, 1965.

Aliev, Kh.Sh., New Species of the Lithocampinae Subfamily from Albian and Cenomanian Deposits of the Northeastern Azerbaijan, *Izv. Akad. Nauk Azerb. SSR, Ser. Nauki o Zemle*, 1968, no. 2, pp. 26–32.

Aliev, Kh.Sh., New Radiolarian Species from the Lower Cretaceous Strata of the Caspian Region in Azerbaijan, in *Voprosy paleontologii i stratigrafii Azerbaidzhana* (Problems of Paleontology and Stratigraphy in Azerbaijan), Baku: ELM, 1976, vol. 1, pp. 114–122.

Aliev, Kh.Sh. and Smirnova, R.F., New Radiolarian Species from Albian Deposits in the Central Russian Platform, in *Iskopaemye i sovremennye radiolyarii* (Fossil and Recent Radiolarians), L'vov: L'vovskii Univ., 1969, pp. 69–72.

Atlas rukovodyashchikh grupp melovoi fauny Sakhalina (Atlas of Guide Groups of the Cretaceous Fauna from Sakhalin), St. Petersburg: Nedra, 1993.

Auerbach, J. and Frears, H., Notice sur quelques passages de l'ouvrage de M.M. Murchison, E. de Verneuil et le comte A. de Keyserling: "Geologie de la Russie d'Europe et des montagnes de l'Oural," *Bull. Soc. Natur. Moscou*, 1846, vol. 19, no. 2, pp. 487–500.

Azizbekova, A.R. and Abbasov, A.B., Population of Planktonic Microorganisms at the Albian–Cenomanian Boundary in the Southeastern Caucasus in *Problemy sovremennoi mikropaleontologii. Trudy 34 sessii VPO* (Problems of Modern Micropaleontology. Proc. 34th Session of the All-Union Paleontological Society), Leningrad: Nauka, 1990, pp. 179–185.

Dan'shin, B.M., *Geologicheskoe stroenie i poleznye iskopaemye Moskvy i ee okrestnostei* (Geology and Mineral Deposits of the Moscow Region), Moscow: Mosk. O–vo Ispyt. Prirody, 1947.

Drushchits, V.V. and Gorbachik, T.N., Albian Deposits in the Eastern Crimea, *Vestn. Mosk. Univ., Ser. Biol., Pochvoved., Geol., Geograf.*, 1959, no. 3, pp. 117–122.

Geologiya SSSR. Tom IV (Geology of the USSR. Volume 4), Moscow: Nedra, 1971.

Kazintsova, L.I., Albian Radiolarians of the USSR, in *Ispol'zovanie radiolyarii v stratigrafii i paleobiologii* (Radiolarians in Stratigraphy and Paleobiology), Ufa: PGO Bashkirgeologiya, 1990, pp. 37–41.

Lipman, R.Kh., Materials on a Comprehensive Study of Radiolarians from the Upper Cretaceous Deposits of the Russian Platform, in *Paleontologiya i stratigrafiya* (Paleontology and Stratigraphy), Moscow: Gosgeolizdat, 1952, pp. 24–51.

Nikitin, S.N., Marks Left by the Cretaceous Period in Central Russia, *Tr. Geol. Kom.*, 1888, vol. 5, no. 2, pp. 1–205.

Olfer'ev, A.G., New Data on Geology of the Lower Cretaceous Deposits in Moscow Region, in *Geologiya i poleznye iskopaemye tsentral'nykh raionov Vostochno-Evropeiskoi platformy* (Geology and Mineral Deposits in the Central Area of the East European Platform), Moscow: Nauka, 1986, pp. 44–55.

Pessagno, E., Radiolarian Zonation and Stratigraphy of the Upper Cretaceous Portion of the Great Valley Sequence, California Coast Ranges, *Micropaleontology*, 1976, no. 2, pp. 1–95.

Pessagno, E., Lower Cretaceous Radiolarian Biostratigraphy of the Great Valley Sequence and Franciscan Complex, California Coast Ranges, *Spec. Publ. Cushman Foundation for Foraminiferal Research*, 1977, no. 15, pp. 1–87.

Putevoditel' ekskursii (XII Evropeiskii mikropaleontologicheskii kollokvium SSSR): Ch. 1, Krym (Guidebook for Excursions of 12th European Colloquium on Micropaleontology in the USSR: Part 1. The Crimea), Moscow: Gos. Biblioteka im. Lenina, 1971.

Rouiller, Ch., *Etudes paleontologiques sur les environs de Moscou, Jubilaeum G. Fischer de Waldheim*, Moscow: Folio, 1847.

Unifitsirovannye stratigraficheskie skhemy nizhnemelovykh otlozhenii Vostochno-Evropeiskoi platformy (Unified Stratigraphic Schemes of the Lower Cretaceous in the East European Platform), St. Petersburg: Roskomnedra, 1993.

Stratigraphy and Geological Correlation, Vol. 5, No. 4, 1997, pp. 342–352. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 4, 1997, pp. 35–45.
Original Russian Text Copyright © 1997 by Glezer, Panova, Tabachnikova, Vyalova.
English Translation Copyright © 1997 by MAIK Nauka/Interperiodica Publishing (Russia).

Correlation of the Eocene Marine Sediments from Northwestern Eurasia (West Siberia and the Volga Region) Based on Microphytofossils

Z. I. Glezer, L. A. Panova, I. P. Tabachnikova, and S. G. Vyalova

All-Russia Research Institute of Geology (VSEGEI), Srednii pr. 74, St. Petersburg, 199026 Russia

Received June 13, 1995

Abstract—Detailed Paleogene stratigraphy is based nowadays on the zonal schemes of different microfossil groups. The specific character of their development and the use of microphytofossil zonations in the regional stratigraphy of various North Eurasian regions within the former USSR are shown using Eocene sediments as an example. In addition to the subglobal nannofossil zonations and the European dinocyst zonation approved by the Interdepartmental Stratigraphic Committee (ISC), we used the zonal schemes based on diatoms and silicoflagellates and the interregional palynostratigraphic scale. The subdivisions of different zonations were correlated to substantiate the stratigraphic position of local and regional stratigraphic units in the standard Eocene scale using Meyen's concept of the chronostratigraphic interchangeability of characteristics.

Key words: *Eocene, zonations, nannoplankton, dinocysts, diatoms, silicoflagellates, spores and pollen*

Nowadays the zonal biostratigraphy of Paleogene marine sediments is largely based on five microphytofossil groups, four of which, namely, nannoplankton, diatoms, silicoflagellates, and dinocysts, were components of the marine biota, the former two being sediment-forming. Though the spore and pollen assemblages reflect the peculiarities of vegetation of the adjacent land, they also play an important role in the subdivision and correlation of marine sediments.

The zonations based on the cited microfossil groups are used both in regional and marine geology, providing a basis for historical geologic and paleogeographic investigations. They enable the subdivision and correlation of the sections of marine carbonate and siliceous sediments widely distributed in the oceans, seas, and on the continents. The zonations based on microphytofossils are usually valid for several sedimentary basins. At the present state of knowledge, the regional zonal stratigraphy, particularly based on planktonic algae, should be considered in close relation to the oceanic Paleogene zonation.

The distinguished zonal units of all groups are generally based on the consecutive changes in taxonomic composition of the assemblages upward the section. Methods of zone age determination and their geographical ranges are specific to each group.

We use the Eocene sediments to discuss the methodological aspects of the development and application of zonal schemes for different sedimentary facies distributed in northern Eurasia, including the Crimea and Caucasus, the Dnieper–Donets depression, the Voronezh anteclise, the Volga region, the Caspian depression, the west Mugodzhary region, the Turgai depression, and the West Siberian lowland. In summary, we suggest the interregional scheme for the detailed subdivision of different Eocene sedimentary facies from northwestern Eurasia, involving zonations of various microphytofossils with zonal units correlated to one another and to the general Eocene scale.

The generalized published data and the results of the authors' long-standing investigations of Paleogene sections from the areas mentioned above served as the basis for the paper.

Nannoplankton, dinocysts, diatoms and silicoflagellates, and spores and pollen were studied by I.P. Tabachnikova, S.G. Vyalova, Z.I. Glezer, and L.A. Panova, respectively.

Nannoplankton

Eocene marine carbonates are exposed in a wide, almost uninterrupted stripe at 43°–45° N, covering the southern regions of the former USSR from the Carpathians to the Kyzyl-Kum in Central Asia. The thick marl and limestone sequences are typical pelagic deposits composed of calcareous tests of coccolithophorids and nannoliths known as nannoplankton.

The low-latitude zonation of Okada and Bukry (1980), based on deep-sea drilling records, and the standard scheme of Martini (1971), derived from the research of the land sections from Europe, North America, and the Caribbean (table), are used for the zonal subdivision of sediments by nannoplankton.

The boundaries of subglobal zones are defined by datum levels, i.e., by events of the appearance and/or disappearance of index species, which are stable, with few exceptions, in subtropical and temperate latitudes of the northern hemisphere. The deposits of each zone yield a certain standard list of species. Zones of both schemes have code numbers.

The modified zonation of Bukry approved by the ISC (refer to the table) is adopted for the Paleogene of the southern regions of the former USSR.

More recently, detailed study has provided new data on the Eocene nannoplankton, particularly for northwestern Eurasia. Some authors (Aubry, 1986; Steurbaut, 1988) revised the stratigraphic distribution and taxonomic composition of the zonal nannoplankton assemblages for the Eocene stages, namely for the Ypresian, Cuisian, Lutetian, and Bartonian.

In early stages of nannoplankton research, the emphasis was on the resemblance of specific composition in vast areas and on the presence of a standard list of zonal species. Further investigations, which embraced the diverse facies and different climatic belts, showed that, in response to the general climatic, biogeographic, and local ecologic factors, the specific composition of nannofossils sometimes varied considerably within a certain zone. The new data enabled some European researchers to describe the peculiarities and difficulties of the zonal boundary definition, using the zonations mentioned above, in different regions of the northern hemisphere, excluding the territory of the former USSR and to consider the possibility and necessity of using additional marker species for the zonal subdivisions of Eocene sediments (Perch-Nielsen and Saunders, 1985). Some papers also considered the number and taxonomic diversity of species in nannoplankton assemblages, indicating the offshore neritic environments and temperatures, and changes in the sedimentation regime upwards of the section (Köthe, 1986).

All the new trends of investigation were taken into account in studies of the Eocene nannoplankton from the southern CIS regions. The detailed investigations, ours included, were first concentrated mainly on the Crimea and Caucasus region, where the major classic sections of marine carbonates of the Lower Paleogene were accumulated (Muzylev, 1980; Bugrova *et al.*, 1988). In recent years extensive information on the nannoplankton from the shelf of northern and northeastern marginal platform seas of Paleogene basins with carbonate-type accumulation was gathered, particularly in the Caspian, southern Transural, and northern Aral regions, where lower and middle Eocene deposits are widespread. Compared to the Crimea–Caucasus area of pelagic carbonate sediments, zonal nannoplankton assemblages in the cited regions have substantial differences associated not so much with the climatic zoning as with facial and bionomic factors. Nannoplankton assemblages of the shallow-water shelf yielded abundant and often extremely diverse species of *Zigodiscus, Rhabdosphaera, Zigrhablithus, Lophodolithus, Nannoturba*, and some other genera. Representatives of these genera were hardly used in zonations as the index species. In the synchronous assemblages from the northern Caucasus, namely, from the Kheu River, they are considerably scarcer, and many of them are missing. A comparison of the lower to lower middle Eocene nannoflora from the northern Caspian, southern Transural, and northern Aral regions with the Ypresian, Cuisian, and Lutetian nannoplankton from the Parisian–Belgian basin, most likely formed in a similar paleogeographic environment of the northern shelf platform, shows their pronounced resemblance.

When Steurbaut and Nolf (1986) revised the Eocene nannoplankton from the Ypresian and Lutetian stratotypes, they took into account the peculiar specific composition of assemblages from the epicontinental sea deposits containing numerous species of the genera mentioned above. This provided the possibility to reveal a number of additional datum levels used to distinguish sixteen (I-XVI) intrazonal units within the *Discoaster binodosus-Nannotetrina fulgens* (NP 11–NP 15) zones of Martini, as well as ten subdivisions in the Ypresian and six in the Lutetian (see table). They were initially considered by the authors as local subdivisions, but further investigations made it possible to trace most of them in sediments of various basins located in the middle and temperate latitudes of the northern hemisphere. In the northeastern Caspian, northern Tobol, southwestern Turgai, and northern Aral regions, twelve intrazonal units of Steurbaut are easily distinguished, which considerably increases the stratigraphic significance of the group and permits detailed direct correlation with the stratotypes of the Eocene stages in the Europe.

Along with the index species used by Steurbaut, we suggest some additional datum levels for the Ypresian of the Caspian region, which are also distinguished in the European Ypresian.

Such a detailed subdivision of the Eocene is of particular importance for sections with terrigenous carbonate and other deposits of the northeastern Caspian region, where the carbonate rocks yielding nannoplankton are represented by various, sometimes rather thin beds.

Whereas both standard zones and the detailed intrazonal units were distinguished and traced in the Ypresian and lower Lutetian epicontinental sea deposits in the Caspian and southern Transural areas, we have a somewhat different situation with respect to the middle Eocene, mostly in the Lutetian and especially in the Bartonian. In these intervals, the nannoplankton is represented by strongly provincial zonal assemblages from the platform sea basins of the Anglo-Parisien stratotype region, the Dnieper and Donetsk depressions, and the northeastern Caspian region.

The upper Lutetian and Bartonian sediments, represented mainly by pelagic facies, are widely distributed

Zonal subdivision of the Eocene sediments in northwestern Eurasia based on microfossils

Series	Subseries	Stage	Plankton zonations: planktonic foraminifers (ISC, 1989)	nannoplankton (Martini, 1971)	nannoplankton (ISC, 1989)	dinocysts (ISC, 1989; Andreeva-Grigorovich, 1994)	diatoms (Z.I. Glezer)	silicoflagellates (Z.I. Glezer)	Interregional spore and pollen zones and beds (L.A. Panova)
Oligocene	lower	Rupelian	*Globigerina tapuriensis*	NP 22	*Helicosphaera reticulata*	*Phthanoperidium amoenum–Wetzeliella symmetrica* DP 12	*Stephanopyxis hyalomarginata*	*Cannopylus binoculus*	beds with Pinaceae, *Q. graciliformis*, *Verrutricolporites*
				NP 21	*Coccolithus subdistichus*		–	–	
Eocene	upper	Priabonian	*Globigerapsis tropicalis*	NP 20	*Discoaster barbadiensis*	*Sphenolithus pseudoradians*	*Bipalla oamarensis*: upper subzone	*Dictyocha hexacantha* s. l.	beds with Pinaceae, *Slowakipollis cf. hippophaeoides*
				NP 19		*Isthmolithus recurvus*	*Cosmiodiscus breviradiatus*	*Dictyocha hexacantha* s. str.	*Q. graciliformis*, *Tricolporopollenites liblarensis*
				NP 18		*Chiasmolithus*	*Cristodiscus succinctus–Coscinodiscus obscurus*		
	middle	Bartonian	*Globigerina turkmenica*	NP 17	*Reticulofenestra umbilica*	*Discoaster saipanensis*	*Rhombodinium porosum* DP 10		*Castanopsis pseudocingulum*, *Q. gracilis*, *Rhoipites granulatus*
			Hantkenina alabamensis	NP 16 c, b		lower subzone	*Dracodinum intermedium*, *Areosphaeridium diktyoplokus* DP 9	*Cosmiodiscus senarius–Coscinodiscus praenitidus–Radialiplicata costulata*	*Dictyocha hexacantha* s. l.: *Corbisema flexuosa*
		Lutetian	*Ac. rotundimarginata*	NP 15 XIVa, XV	*Nannotetrina fulgens*	*Rhombodinium draco–Wetzeliella articulata* DP 8	*Paxilla oligocaenica*: *Stephanopyxis crenata*	*Dictephanus antiquus*: *Naviculopsis punctilia*	beds with *Castanea crenataeformis*, *Pompeckjoidaepollenites subhercynicus*
			Acarinina bullbrooki	NP 14 XIV, XIII–XI	*Discoaster sublodoensis*; *Rhabdosphaera inflata* lower subzone	*Charlesdowniea coleothrypta* s. l. DP 7; *C. coleothrypta rotundata*; *C. coleothrypta*	*Paxilla oligocaenica*: lower subzone; *Brightwellia hyperborea*	*Dictyocha secta*	*C. crenataeformis*, *S. constans*
	lower	Ypresian	*Globorotalia aragonensis*	NP 13	*Discoaster lodoensis*		*Coscinodiscus decrescens*	*D. rotundata*	*C. crenataeformis*, *Platycaryapollis anticyclus*, *Sapotaceae*
				NP 12 IIIb–VIII	*Marthasterites tribrachiatus*		*Coscinodiscus payeri*	*Dictyocha frenguellii carentis*	
			Globorotalia subbotinae	NP 11 I–IIIa	*Discoaster binodosus*	*D. varielongitudum* DP 6	*Coscinodiscus josephinus*		*Plicapollis pseudoexcelsus*, *Interpollis supplingensis*, *Triporopollenites robustus*
				NP–10	*Discoaster diastypus*; *Marthasterites contortus*	*Dracodinium similis* DP 5; *Wetzeliella meckelfeldensis* DP 4	*Hemiaulus proteus*: upper subzone	beds with *N. aspera*, *N. foliacra*	
Paleocene	upper	Thanetian	*Acarinina acarinata*	NP 9	*Discoaster multiradiatus*; *Marthasterites bramlettei*	*Apectodinium homomorphum* DP 3	*Stictodiscus kossuthii*	*Naviculopsis constricta* sp. str.	*Nudopollis terminalis*, *Trudopollis menneri*, *Subtriporopollenites*
					lower subzone		*Trinacria muricata*		

in the Crimea and Caucasus, and in the southeastern Caspian, Ustyurt and Aral regions.

The upper subzone of the *Discoaster sublodoensis* Zone is almost universally identified here as the *Rhabdosphaera inflata* Br. et Sull Biozone. The overlying *Nannotetrina fulgens* Zone lacks the three-membered structure in contrast to the same unit in low latitudes. The lower boundary of the zone is often defined by the first appearance of *Nannotetrina* representatives, since the index species *Nannotetrina fulgens* is usually very scarce or completely absent. The Bartonian corresponds to the large *Reticulofenestra umbilica* Zone of Bakry with two subzones. They approximately correspond to Martini's zones NP 16 and NP 17. As a whole, the zonal assemblage of Zone NP 16 is quite distinguishable, but its boundaries can hardly be uniquely defined.

Rhabdosphaera gladius, the species marking the base of the *Discoaster tani nodifer* Zone NP 16, is often missing in pelagic sediments or has a different stratigraphic distribution. The same is true for *Chiasmolithus solithus* (Br. et Sull.) Lock., whose disappearance marks the top of the zone.

Therefore, the recognition of the interval corresponding to zones NP 16 and, partly, NP 17 in the Eocene sections of the Crimea, Caucasus, northwestern Europe, and particularly of the Caspian region, cannot be based on the criteria defined by Martini, and accordingly other, often local index species are used for this purpose. The assemblages of Zone NP 16 in some regions, for example, in the deposits of the Kiev Formation from the Dnieper–Donets depression, are characterized by extreme diversity, especially of discoasters, and include many endemic forms. This enables the recognition of three subzones here, namely, NP 16a, 16b, and 16c (see table), though many datum levels in use are of a completely local character (Dang Dyk Nga, 1973).

The middle–upper Eocene (Bartonian–Priabonian) boundary is defined by a rather stable and universal first occurrence level of *Chiasmolithus camaruensis* at the top of Martini's Zone NP 17. The upper Eocene nannoplankton assemblages of the *Discoaster barbadiensis* Zone with the three subzones NP 18–20 of Martini are widespread in the thick limestones of the Belaya Glina Formation of the Crimea and Caucasus. Their taxonomic composition is rather homogeneous throughout this vast distribution area. The synchronous assemblages from the southeastern Caspian region are likely very similar to them.

The upper *Sphenolithus pseudoradians* Subzone is almost everywhere distinguished as "beds," because its index species is usually very scarce. According to most data, the Eocene–Oligocene boundary, defined by the disappearance of rosettelike discoasters, coincides with that of foraminifers and with a drastic facies change at the boundary of the Belaya Glina and Pshekha horizons in the Northern Caucasus. On occasion, for example, in the southeastern Caspian region, the rosettelike discoasters are so rare at the top of the *Sphenolithus pseudoradians* Subzone that their extinction moment, i.e., the Eocene–Oligocene boundary, is difficult to define.

Therefore, the wide, sometimes intercontinental, extension of the nannoplankton datum levels recorded in the lower and lower middle Eocene enabled the distinction of common intrazonal subdivisions in the closely allied types of sections of different epicontinental seas. This makes the correlation substantially more faithful and the nannoplankton biostratigraphic subdivision more detailed; it also permits the establishment of paleobiogeographical relations.

The great diversity of deposits and paleogeographical environments of the late middle Eocene time, namely, of the late Lutetian and Bartonian, presents difficulties in the boundary definition of even standard zones. The datum levels of species with limited distribution areas often have to be used for these purposes.

In the upper Eocene deposits of the southern regions with the widespread pelagic facies, the standard zones are easily distinguished, and the taxonomic composition of zonal assemblages differs little in vast areas.

Dinocysts

Fossil dinoflagellate cysts occur in different marine facies, which enables their use for the stratigraphic subdivision of sediments and for wide interregional correlations.

The zonal scheme based on dinocysts was developed for the Paleogene sediments of the West European platform (Chateauneuf and Cruas-Covagnetto, 1978). Later it was included in the Paleogene stratigraphic correlational scheme (PSCS) (Cavelier and Pomerol, 1986) along with the zonations based on other microfossil groups. Thirteen dinocyst zones, from W1 to W13, were distinguished in the Eocene according to the changes of the Wetzeliaceae taxonomic composition.

Costa and Manum (1988) also suggested dinocyst zonation for the Paleogene basins of northwestern Europe. They identified 7 zones, from D6 to D12, and 4 subzones in the Eocene. The zones were distinguished according to the change in the taxonomic composition of the assemblage, and the subzones, by the species appearance or extinction events. The zones of the scheme were correlated with the Eocene nannoplankton zonation of Martini. In addition to zonal schemes of the European Paleogene, the dinocyst biozonations for the Paleogene basins of the North Atlantic, northeastern Atlantic, and North America were developed (Andreeva-Grigorovich, 1994).

Based on the PSCS, Andreeva-Grigorovich (1994) subdivided the Eocene sections from the Carpathians, Crimea and Caucasus region, northern Black Sea region, Northern Caucasus, and eastern Caspian area, and distinguished dinocyst assemblages and zonal species comparable to those from Europe and other regions

of the Earth. In the sediments studied, she identified three zones, DP 4, DP 5, and DP 6 (named from dinocysts of the Paleogene), and the subzone DP 7a, which she correlated with the Costa and Manum's zones and with the corresponding zones of the PSCS.

Changes in biozonal assemblages in the European stratotypes of the Paleogene stages served as a criterion for the recognition of the biozones, whereas their boundaries were defined by the first or last occurrence of the index species coinciding with the nannoplankton zonal boundaries.

The index species of the corresponding subdivisions of the PSCS were primarily used for the zone designations. However, not all corresponding zones are of completely equal range.

The *Charlesdowniea coleothrypta* s.l. Zone DP 7 is subdivided into two subzones: *Charlesdowniea coleothrypta* (DP 7a) and *Ch. coleothrypta rotundata* (DP 7b). The lower Subzone DP 7a corresponds to the *Kisselevia coleothrypta* Zone W6, and the upper Subzone DP 7b to the *Kisselevia coleothrypta rotundata* W7 and *Kisselevia fasciata* W8 zones. The *Charlesdowniea clathrata angulosa* Zone DP 11 corresponds to the zones W12–13. The different genera names therewith result from the revision of the *Kisselevia* Vozzh. genus with the distinction of the new genus *Charlesdowniea* Vozzh. et Lentin.

In the Eocene deposits of the West Siberian lowland, Kul'kova (1994) recorded the first occurrences of the zonal species known from the Paleogene stratotypes of Western Europe and from the southern CIS. Additionally, she identified the *Charlesdowniea fasciata* Zone, which was not detected in the southern CIS. The stratigraphic position of the last zone corresponds to that of the *Kisselevia fasciata* Zone W8 of the same age. These assemblages yield, along with the European forms, the following characteristic West Siberian species: *Rhombodinium corociatum* Vozzh., *Wetzeliella irtyschensis* Alb., and *Kisselevia ofnata* Vozzh. Kul'kova recorded the first occurrence levels of the zonal species known from the European stratotypes. The zones distinguished by Kul'kova are characterized by two or three European index species, which successively appeared in the sections, and their ranges correspond to several European dinocyst zones.

In the southern Ural region, Vasil'eva (1990) recorded the zones of PSCS and also found the West Siberian dinocysts in the zonal assemblages. In particular, she distinguished the *Kisselevia ornata* Zone.

Thus, the biostratigraphic levels of the European and West European schemes were traced up to West Siberia.

Diatoms and Silicoflagellates

Diatoms and silicoflagellates are the leading phytoplankton groups for the development of the zonal biostratigraphy of siliceous deposits. These deposits of the Eocene age are widely distributed as vast stripes and spots traceable from the Antarctic to northern Polar regions. The organogenic siliceous sediments are represented by diatom oozes of oceanic and open sea origin and by diatomites and diatomaceous shales in sections of northern Europe, different regions of the East European Platform, the western Mugodzhary, the northeastern Caspian region, the Turgai Trough, and some areas of the West Siberian lowland.

The siliceous phytoplankton zonations were developed concurrently for the oceanic and open sea sediments and for deposits distributed in the regions of the former USSR listed above. Most of the oceanic and regional schemes are of a local character. The extension of the zonal units is limited to a corresponding area or province.[1] For instance, oceanic diatom zonations were suggested (Fenner, 1984, 1985) for the large biogeographic areas, namely, for the low and high latitudes of the southern hemisphere. The Eocene zonations for the Norwegian Sea (Schrader and Fenner, 1976; Strel'nikova, 1992) are indubitably provincial. The interregional Paleogene diatom and silicoflagellate zonations initially were developed for an individual paleogeographic area (Glezer, 1979a, 1979b; *Zonal'naya stratigrafiya...*, 1991).

Though suggested for the low latitudes of the oceans, the silicoflagellate zonation of Bukry (1981) is, in essence, of subglobal character, as its zonal subdivisions correspond to the Eocene subseries or to the integral parts of different subseries and are based on the evolutionary replacement of species. The diatom zonation suggested by Strel'nikova (1992) for the whole northern hemisphere mechanically combines the minor zonal subdivisions distinguished by different authors in various oceanic regions and in some areas of the former USSR, which are often not contiguous and not correlated to one another convincingly enough.

Datum levels are widely used for the distinction of various zones, particularly in the oceanic zonations (*International Stratigraphic Guide*, 1976; *Stratigraficheskii kodeks SSSR*, 1992). This is reasonable for the elaboration of zonal schemes for a certain biogeographic area (province) with the unobstructed and almost simultaneous dispersal of species from the centers of their origin. In silicoflagellate zonations, the appearance levels of species can be defined through an examination of their phylogenetic relations. The diatom phylogeny is almost unstudied, and the earliest finding is commonly taken as the first occurrence. In most cases, the appearance events of a certain species recorded in different zonations represent the onset of favorable conditions in the corresponding areas. These events are not always synchronous, which is of prime importance for the correct use of oceanic zones in the regional stratigraphy. A thorough study of the evolu-

[1] In this case, the terms "biogeographic area" and "biogeographic province" are not exactly defined because the biogeographic subdivision of the Paleogene according to the siliceous phytoplankton is not developed.

tionary appearance of a species and of its migration ways resulting from the combined biotic and abiotic factors is required for the justified distinction of zones common for the oceanic and terrestrial deposits.

We took into account the regularities of the historical development of algae floras distributed in the oceanic and platform basins (Glezer, 1979a, 1980, 1994) to make more refined and detailed the interregional zonations previously suggested.

The specific composition of the algae assemblages replacing each other in the Eocene sections of the regions under study was in close and variable biogeographical relations with the oceanic floras. Whereas the early Eocene oceanic floras are virtually unknown and the algae of the platform basins were developed autonomously throughout almost the whole early Eocene, at the end of this period the exchange between these and oceanic species began and increased during the middle Eocene to reach its maximum in the Bartonian. The maximum development of oceanic diatoms occurred in the Bartonian, whereas in the platform marine basins the flora flourished throughout the whole Eocene. Most species in the Bartonian epicontinental sea floras are common with the oceanic taxa.

Because of the peculiar Eocene diatom evolution noted above, different authors have no doubt on the local character of the zonal units in the lower Eocene regional stratigraphic schemes. At the same time, the possibility of distinguishing the oceanic zones in the Bartonian requires further discussion.

Based on the study of bio- and teilezones of species common with the oceanic flora, the following four species groups of different significance for the zonal stratigraphy were distinguished among the diatoms of the platform basins of the second half of the middle Eocene.

(1) Considerably numerous species are common in the algae assemblages of platform basins and characterized by well-pronounced teilezones. Most of them are diagnostic in different middle Eocene zonations: *Stephanopyxis superba* Grun., *Coscinodiscus decrescens* Grun., *Brightwellia hyperborea* Grun., *Bipalla oamaruensis* (A.S.) Gles., *Cristodiscus succinctus* (Sheshuk. et Gles.) Gles. et Olscht., *Sheshukovia condecora* (Brightw.) Gles., *Hemiaulus polycystinorum* Ehr., *Peponia barbadensis* Grev., and others. By the detailed study of stratigraphic distribution, some species of this group can be used for the distinction of subglobal zonal units.

(2) Some index species of the oceanic zonations have a limited occurrence in the platform basins. Their distribution exhibits a certain regularity. For instance, the first occurrence of scarce *Lisitzinia* (*Triceratium*) *inconspiqua* var. *trilobata* (Fenner) Gles. and *Craspedodiscus oblongus* (Grev.) Hanna was recorded at approximately the same level as in the oceans and is associated with the beginning of the Eocene migration. They were found at the base of the *Brightwellia hyperborea* Zone and in the *Pyxidicula cruciata* Subzone, the former typical of the West Siberian Lowland and central Volga region, and the latter characteristic of the eastern Caspian region. The species appeared again in almost all the Bartonian flora localities.

(3) There is also a number of forms that include the index species of the middle Eocene oceanic zonation, namely, *Lisitzinia kanayai* (Fenner) Gles., *Brightwellia imperfecta* Jousé, *Rhylandsia biradiata* Grev., *Triceratium unguiculatum* Grev., *Asterolampra marylandica* Ehr., *Rutilaria lymoniformis* Ross., and others representing exotic elements in the platform basin floras and unusable as zonal markers because of their scarce occurrence.

(4) A large group of conservative species characterized by several epiboles is associated with the different Paleogene series within a single or various biogeographical regions (provinces). Though some species of the group, namely, *Trinacria excavata* cf. *tetragona* A.S. and *T. subcapitata* (A.S.) Grun., are used in the middle Eocene zonal stratigraphy, they should be considered as diagnostic only for the local units.

Representatives of each group can be used for paleogeographic reconstructions and for more complete characterization of the biota.

We should emphasize that the first and last occurrence of species recorded by findings from the studied sections do not correspond to the moments of their evolutionary appearance or extinction (Glezer, 1980). As Meyen (1989, p. 165) justly noted, the appearance event "... can only bear witness to the incorporation of the species in the paleoecosystem of a certain stratigraphic unit." Thus it is very difficult to reveal a species, especially a group of species, whose teilezone ranges and boundaries closely coincide in the separated basins of different biogeographic areas, namely, in the oceans and open and epicontinental seas with different paleogeographical environments. This is supported by numerous records on siliceous phytoplankton zonal stratigraphy. We consider two examples.

The easily detectable and widespread *Pyxilla gracilis* Temp et Ferti is used as the index species of zones distinguished by means of different criteria. Thus, in the lower Ob' River region, Rubina and Droznes (1961), who used species quantity as an important parameter, distinguished local zones with its "common" and "abundant occurrence," which approximately correspond to the recent zones NP 13 and NP 14. The analogous local zones distinguished by changes in the diatom assemblage (Glezer, 1979a; *Zonal'naya stratigrafiya...*, 1991) is at the same level. Strel'nikova (1992) lowered the base of the zones using the first occurrence of species within the underlying combined *Coscinodiscus payeri* Zone that approximately corresponds to the lower Eocene zones NP 11 and NP 12. However, it turned out that, in Denmark (Fenner, 1994) and in the Indian Ocean (Fourtanier, 1991), the species first appeared at the very beginning of the early Eocene,

in Zone NP 10. Therefore, the synonymous zones in the oceans and platform basins have different stratigraphic positions, though within the early Eocene. In consideration of all the cited facts, we rejected the distinction of the *P. gracilis* Zone in the zonation proposed for northern Eurasia.

The detailed study of the global oceanic *Dictyocha hexacantha* Zone shows that its synchroneity in the ocean and in the middle Eocene sections of the platform regions is very complicated to establish, even with the occurrence of more than one widespread diagnostic species. In the sections of the eastern Caspian region (Glezer, 1979b) and the Voronezh anteclise the index species turned out to appear substantially later than forms, the combined occurrence of which permitted Bukry (1981) to distinguish the zone in the ocean. According to peculiarities of the zonal species stratigraphic distribution, the proposed zonation (table) includes two zones, *Dictyocha hexacantha* s.l. and *D. hexacantha* s.str., with different range and stratigraphic positions within the middle Eocene in the oceanic and platform basins.

From the analysis of the global biostratigraphic records on diatoms and silicoflagellates, we consider the development of zonations for certain biogeographic areas or provinces and the correlation of their zonal subdivisions to be more justified in the present state of knowledge. The taxonomic composition of zonal assemblages and the regularities of its variations result not only from the evolution of taxa, but to a greater extent from the complicated interaction of abiotic factors specific for every sedimentary basin and biogeographic area. However, more general factors responsible for the algae flora development were active as well. Therefore it is possible that in the future, in certain stratigraphic intervals characterized by close biogeographic relations of floras from different basins, we will distinguish "subglobal" zonal units using the common species of the first group mentioned above. However, this would first require the elucidation of diatom species phylogeny based on the study of their morphogenesis by means of an electron microscope.

The proposed substantially refined and detailed diatom and silicoflagellate zonations for the Eocene of western North Eurasia were developed based on the regular changes of the algae species composition in the regions of a single biogeographic area. We used as index and diagnostic species the typical forms widely distributed and common at a certain stratigraphic level, taking regard of their evolutionary succession. Preference was given to the species whose earliest findings in the studied material coincided with the beginning of their adaptive radiation.

Many characteristic zonal species are common to the oceanic flora. However, only the *Brightwellia hyperborea* Zone and the *Cristodiscus succinctus* Subzone are named according to the index species of the corresponding oceanic units of the middle Eocene zonations for the Blake Plateau, Site 390A. According to the nannoplankton records from the same site (Bukry, 1978), the *Brightwellia hyperborea* diatom interval corresponds to the nannoplankton zones NP 14 and NP 15. In the Blake Plateau sediments, the *Cristodiscus* (*Coscinodiscus*) *succinctus* beds were recorded in the 2-cm layer, and their boundaries were not defined. They correspond to either the top of Zone NP 15 or Zone NP 16 (Strel'nikova, 1992). In the sections studied, the subdivisions under discussion have a similar but somewhat different stratigraphic position (see table).

Both of the species are chosen because they are good markers in the middle Eocene sections of different regions.

The most reliable datings of the interregional siliceous phytoplankton zones (table) are based on their relationship with the planktonic foraminifer, nannoplankton, and dinocyst zones distinguished in the same sections. These data were obtained by the comprehensive study of materials from the eastern Caspian region (Bugrova *et al.*, 1997), the Dnieper–Donets depression, and the West Siberian lowland.

Spores and Pollen

Palynologic records play an important role in the regional stratigraphy of both marine and continental Eocene sediments of different composition.

The palynostratigraphic scales were first developed by West European palynologists (Krutzsch, 1966; and others) who studied the stratotypes of the Paleogene stages in western and central Europe. The suggested zonations appeared to be regional, and it was rather difficult to define clearly the palynozone boundaries, even in their distribution areas. However, they can be used for wide correlations. The detailed middle–upper Eocene and Oligocene zonation of Chateauneuf (1980) for the Parisien basin, which includes nine palynozones correlated with the dinocyst zones, is also difficult to use because the taxa selected by the author for the distinction and substantiation of the zones are scarce or completely missing in the sediments of the same age from our sections. Therefore, the palynozone boundaries and range are difficult to establish. Only the early Oligocene *Pytiosporites* Zone 7 is easily distinguished and traced throughout all the former USSR, namely, in Ukraine, the European part of Russia, West Siberia, and other regions.

The interregional Paleogene miospore zonation for northwestern Europe (*The Northwestern...*, 1988) is less detailed. To distinguish eight zones, the authors chose 38 large taxa of angiosperm pollen, namely, specific and generic groups. The zonation is based on the first and last occurrence of certain taxa. In our opinion, the choice of taxa was extremely inadequate. The authors distinguished in the Eocene only two zones, namely, SP 4 with three subzones within the lower and

middle Eocene, and SP 5 corresponding to the second half of the middle and to the upper Eocene. The Zone SP 4 was distinguished according to the first occurrence of *Diporites iskaszentgyorgyi, Spinizonocolpites, Dicolpopollis, Bombacacidites*, and *Reevesiapollis* Groups, which are extremely scarce in the lower Eocene of the Crimea, Caucasus, and of other areas of southern Russia. A great many zonal species have a wider stratigraphic range, for instance, *Nudopollis endangulatus* Pf. occurred up to the middle of the middle Eocene, whereas in our sections, it is missing above the base of the upper Paleocene.

In the attached regional Eocene schemes for separate regions of the Northwest European countries, a unified comprehension of the boundary between zones SP 4 and SP 5 and, particularly, between the lower and middle Eocene is not always seen. The scheme is also difficult to use for detailed stratigraphy. However, the zonal assemblages yield some taxa whose wide distribution areas were recorded within the eastern Tethyan paleofloral area and can be used for correlation purposes. Despite the impossibility of using the European palynostratigraphic schemes in northern Eurasia within the former USSR, regional Eocene miospore zonations were suggested for the West Siberian lowland and Kazakhstan. Most of their zonal units are also correlated at the subseries level; some of them are correlated with the zonations of other faunal and floral groups (*Zonal'naya stratigrafiya*..., 1991). The comprehensive study of the Eocene stratigraphy of the northern Caucasus, Kazakhstan, and southern West Siberia using the miospores and dinocysts (Krasheninnikov *et al.*, 1989; Akhmet'ev *et al.*, 1992; and others) will permit us to detail the available palynologic zonations.

The Paleogene, in particular, Eocene palynostratigraphic schemes for the northern Caucasus and the Bakhchisarai region of the Crimea, correlated with the standard planktonic zones and with the dinocyst zonation for southern Russia (*Postanovleniya MSK*..., 1989), are nowadays the most justified. Seven palynozones were identified in the Eocene miospore zonation (refer to the table) included in the proposed interregional correlational scheme for southern Russia, the Russian platform, and the adjacent CIS regions.

The palynozones are named after their most typical and widespread species, confined to certain stratigraphic levels. We usually used their first occurrence levels, but in some cases, the last occurrence events were taken for the most characteristic.

The proposed units represent combined zones. Their boundaries correspond to the levels of substantial changes in zonal assemblages that resulted from both palynoflora evolution and paleogeographic or paleoecologic environmental events. The zonal units were correlated by the presence of common or similar characteristic taxa in the assemblages. The palynozone ranges vary between one and two foraminifer zones. The age was determined by the joint occurrence with nannoplankton, foraminifers, dinocysts, and diatoms, the latter being especially significant in the West Siberian sections.

Two palynozones were distinguished in the lower Eocene. The lower zone with the index species *Plicapollis pseudoexcelsus, Integrpollis supplingensis,* and *Triporopollenites robustus* corresponds to the *Globorotalia subbotinae* Zone in the northern Caucasus. The base of the zone was defined by the abrupt decrease of *Normapolles* taxa, for instance, by the disappearance of *Trudopollis menneri*, and by the increased abundance of the triporate pollen (Panova, 1988). The upper palynozone with *Castanea crenataeformis, Platycaryapollis anticyclus,* and Sapotaceae is distinguished in the northern Caucasus within the *Globorotalia aragonensis* Zone range. It is characterized by the increased role of the tricolporate pollen of *Tricolporopollenites cingulum, Retitricolpites*, Sapotaceae, and others, by the continued diversity of *Triatripollenites* and *Subtriporopollenites* species, namely, of *S. subporatus, S. magnoporatus,* etc., and by the appearance of *Pentapollenites* and *Nyssapollenites* pollen (*Prakticheskaya palinostratigrafiya,* 1990).

In the Voronezh syneclise and Dnieper–Donets depression of the Russian Platform (the Kanev Formation) one regional *Plycapollis pseudoexcelsus–Triporopollenites robustus–Platycaryapollis trisolutionis* Zone of similar composition, but with some regional peculiarities, was identified. Further eastward in the Turgai and Irtysh regions, the Pavlodar area, and West Siberian lowland, two palynozones were also recorded in the lower Eocene and correlated using the characteristic taxa. Two palynozones were distinguished in the Lutetian of the middle Eocene. The base of the lower *Castanea crenataeformis–Subtriporopollenites constans* Zone is defined by a sharp increase of the tricolporate pollen of *Tricolporopollenites cingulum* (R. Pot.) R. Pot, *T. fagoides* W.Kr., *Araliaceoipollenites,* and others, and by the raised diversity of subtropical plants, namely, of *Sabalpollenites, Myrica, Liquidambar,* Myrtaceae and others. The age of the palynozone was elucidated by the joint occurrence of pollen with the foraminifer assemblage of the *Acarinina bullbrooki* Zone in the Crimea and Caucasus regions. The base of the upper *C. crenataeformis–Pompeckjoidaepollenites subhercynicus* Zone was recorded by the absence of the following taxa: *Subtriporopollenites magnoporatus* Pf., *Basapollis basalis* Pf., *Interpollis supplingensis* W. Kr., and some others. The zone range corresponds to that of the *Acarinina rotundimarginata* Zone in the middle Eocene sections from the Northern Caucasus, the Crimean Bakhchisarai region, and the Dnieper–Donets depression. Two palynozones distinguished in the first half of the middle Eocene are well traced in the Eocene sections in the West Siberian lowland and northern Kazakhstan. In the Bartonian of the middle Eocene, the single *Castanopsis pseudocingulum–Quercus gracilis–Rhoipites granulatus* Zone was identified. This resulted from the imperfect investigation of

the uppermost middle Eocene sections in the Russian platform and the adjacent northern Ukraine regions.

The base of the zone is marked by the complete disappearance of the *Normapollis* stem from the pollen assemblage, and by the appearance of *Quercus gracilis, Q. graciliformis* Boitz, *Rhus regularis* Pan., *Rhoipites granulatus* Fred., *Nyssa crassa* Pan., different *Scabratricolporites*, and other forms.

In the Bartonian of the Northern Caucasus two zones were distinguished (*Zonal'naya stratigrafiya...*, 1991) with their age determined by the joint occurrence of pollen with the foraminifer assemblage of the *Hantkenina alabamensis* and *Globigerina turkmenica* zones. In the West Siberian sections, two palynozones were also identified, which were dated by means of the dinocyst assemblage of the DP 9 and DP 10 zones.

Two palynostrata were distinguished in the upper Eocene. The lower one is represented by the *Quercus graciliformis–Tricolpopollenites liblarensis* Zone with its lower boundary recorded by an abrupt increase of the zonal taxa and by the appearance of moderately thermophilic floral forms. The zonal assemblages of West Siberia and northern Kazakhstan are characterized by the appearance of *Hydropteris indutus* spores. The early Eocene taxa completely disappeared here. The age of the zone was established according to the joint occurrence of pollen with the foraminifer assemblages of the *Globigerapsis tropicalis* Zone (*Prakticheskaya palinostratigrafiya*, 1990) and with the dinocysts of Zone DP 11 in West Siberia, Turgai, and other regions. In the Northern Caucasus, Volga region, West Siberia, and some other areas, the Pinaceae and *Slowakipollis* cf. *hippophaeoides* beds were recorded in the uppermost upper Eocene. Their lower boundary is defined by the slight increase of the gymnosperm pollen, namely, of Pinaceae, Taxodiaceae, *Ephedra*, and others, and by the appearance of new taxa *Slowakipollis* cf. *hippophaeoides, Verrutricolporites, Quercus conferta* Boitz., etc. The age of the beds corresponds to the top of Zone DP 11 and to the *Bolivina antegressa* Zone.

The top of the beds, like the upper Eocene–lower Oligocene boundary, is marked by the change of assemblages, manifested by the abrupt increase up to 85% of the pollen of Pinaceae and Taxodiaceae. In addition, the boundary coincides with the base of the dinocyst *Phthanoperidinium amoenum* Zone DP 12.

CONCLUSION

As indicated above, each microphytofossil group has certain peculiarities of its use for the Eocene biostratigraphy. They result from the biologic features of the group and from biogeography, distribution areas of the assemblages and separate species, stratigraphic range of their teile- and biozones, and from the facies confinement of fossil remains.

The zonation of every group is based on the regular changes in the microphytofossil assemblages within vast biogeographic areas (provinces), which partly or completely embrace areas of northwestern Eurasia within the former USSR.

The possibility of using, with some additions, the subglobal Eocene nannoplankton zonation of Bukry, the standard scheme of Martini with intrazonal units of Steurbaut, and the dinocyst zonation developed for Western Europe enables the direct correlation of the Eocene deposits in the areas studied with the stratotypes of the Eocene stages.

The proposed local interregional zonations of diatoms and silicoflagellates, whose units are correlated with the nannoplankton and dinocyst zones, permit the substantiation of the stage division of the marine siliceous sediments widespread in northwestern Eurasia. Moreover, the correlation of the diatom and silicoflagellate zones with the corresponding units of the oceanic zonations using the widespread common species provides additional data for their age determination.

Owing to the correlation of palynozones with the nannoplankton and dinocyst zones, the interregional spore and pollen zonation also makes it possible to correlate the sections with different sedimentary facies in various regions and to compare them with the European stages.

The correlation of the zonal units of different microphytofossil groups with the planktonic foraminifer zones and the Eocene stages and subseries is presented in the table. Based on Meyen's (1989) concept of the chronostratigraphic interchangeability of characteristics, in this instance of biozones, one can substantiate the position of local or regional stratigraphic units in the standard stratigraphic scale. The records cited can be used for paleogeographic reconstructions as well.

REFERENCES

Akhmet'ev, M.A. and Zaporozhets, N.I., The Oligocene Climates of the Eastern Crimea–Caucasus Region and Kazakhstan, *Izv. Ross. Akad. Nauk, Ser. Geol.*, 1992, no. 3, pp. 5–24.

Andreeva-Grigorovich, A.S., The Paleogene Dinoflagellate Zonation for the Southern Regions of the CIS, *Al'gologiya*, 1994, vol. 4, no. 2, pp. 66–76.

Aubry, M.P., Paleogene Calcareous Nannoplankton Biostratigraphy of Northwestern Europe, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1986, vol. 55, nos. 2–4, pp. 267–334.

Bugrova, E.M., Glezer, Z.I., Panova, L.A., and Tabachnikova, I.P., Biostratigraphy of the Paleocene and Eocene Sediments of the Eastern Caspian Region Based on Microfossils, *Region. Geol. Metallogen.*, 1997, no. 6.

Bugrova, E.M., Nikolaeva, I.A., *et al.*, On the Paleogene Zonal Division in Southern Regions of the USSR, *Sov. Geol.*, 1988, no. 4, pp. 96–107.

Bukry, D., Cenozoic Coccolith, Silicoflagellate, and Diatom Stratigraphy: Deep-Sea Drilling Project, Leg 44, *Initial Rep. Deep Sea Drill Proj.*, 1978, vol. 44, pp. 807–863.

Bukry, D., Synthesis of Silicoflagellate Stratigraphy for Maestrichtian to Quaternary Marine Sediments, *SRPM. Spec. Publ.*, 1981, no. 32, pp. 433–444.

Cavelier, C. and Pomerol, C., Stratigraphie du Paléogéne, *Bull. Soc. Geol. Fr. Sec. 8*, 1986, vol. II, no. 2, pp. 255–261.

Châteauneuf, I.I., Palynostratigraphie et paleoclimatologie de l'Eocene superieur et de l'Oligocene du bassin de Paris (France), *Mem. BRGM*, Paris, 1980, no. 116.

Châteauneuf, S.S. and Gruas-Cavagnetto, C., Les zones de Wetzeliellaceae (Dinophyceae) du bassin de Paris, *Bull. BRGM*, 1978, ser. 4, no. 2, pp. 59–93.

Costa, L.I. and Downie, Ch., The Distribution of the Dinoflagellate *Wetzeliella* in the Paleogene of Northwestern Europe, *Palaeontology*, 1976, vol. 19, no. 4, pp. 591–614.

Costa, L.I. and Manum, S.B., The Description of the Interregional Zonation of the Paleogene (D1–D15) and the Miocene (D15–D20), *Geol. Jahrb.*, 1988, vol. 100, pp. 321–330.

Dang Dyk Nga, Calcareous Nannoplankton of the Kiev Formation from the Dnieper and Donets Depression in the Northern and Northwestern Margins of the Donets Fold Structure, *Cand. Sci. (Geol.-Mineral.) Dissertation*, Khar'kov: Khar'kov State Univ., 1973.

Fenner, J., Eocene–Oligocene Planktic Diatom Stratigraphy in the Low Latitudes and the High Southern Latitudes, *Micropaleontology*, 1984, vol. 30, no. 4, pp. 319–342.

Fenner, J., Late Cretaceous to Oligocene Planktic Diatoms, in *Plankton Stratigraphy*, London: Cambridge Univ. Press, 1985, pp. 713–762.

Fourtanier, E., Paleocene and Eocene Diatom Biostratigraphy and Taxonomy of Eastern Indian Ocean Site 752, *Proc. Cean Drill. Program: Sci. Results*, 1991, vol. 121, pp. 171–187.

Glezer, Z.I., The Zonal Subdivision of Paleogene Sediments Based on Diatom Algae, *Sov. Geol.*, 1979a, no. 11, pp. 19–30.

Glezer, Z.I., The Zonal Subdivision of the Paleogene in the Mediterranean Paleobiogeographical Region within the USSR Based on Siliceous Flagellate Algae, *Trudy XIX sessii Vsesoyuznogo paleontologicheskogo obshchestva* (Proc. XIX Session All-Union Paleontol. Soc.), Leningrad, 1979b, pp. 29–42.

Glezer, Z.I., Regularities of the Diatom Historical Development and Their Significance for the Biostratigraphy, *Tr. Vseross. Nauchno–Issled. Geol. Inst. (VSEGEI). Nov. Ser.*, 1980, vol. 305, pp. 94–105.

Glezer, Z.I., Correlation of the Paleogene Diatom Evolutionary Stages in the Epicontinental Marine and Oceanic Basins, *Stratigr. Geol. Korelyatsiya*, 1994, vol. 2, no. 1, pp. 103–107.

Glezer, Z.I., The Interrelation Between the Eocene Diatom Flora Evolution and Some Environmental Factors, *Stratigr. Geol. Korelyatsiya*, 1996, vol. 4, no. 4, pp. 83–94.

International Stratigraphic Guide, Hedberg, H., Ed., New York: Wiley, 1976. Translated under the title *Mezhdunarodnyi stratigraficheskii spravochnik*, Moscow: Mir, 1978.

Köthe, A., Kalkiges Nannoplankton aus dem Palaogen Nordwestdeutschlands, *Geol. Jahrb.*, 1986, vol. 89.

Krasheninnikov, V.A., Zaporozhets, N.I., and Kurgalimova, G.T., Correlation of Different Sedimentary Facies of the Upper Eocene and Lower Oligocene (Oceans and Continents), in *Problemy stratigrafii verkhnego proterozoya i fanerozoya* (Stratigraphical Problems of the Upper Proterozoic and Phanerozoic), Moscow: Nauka, 1989, pp. 199–219.

Krutzsch, W., Die Sporenstratigraphische Gliederung des Altetertiar im nordlichen Mitteleuropa (Palaozan-Mitteloligozan), *Abh. Zentr. Geol. Inst. Berlin*, 1966, vol. 8, pp. 156–157.

Kul'kova, I.A., Marine Paleogene Dinocysts from the West Siberian Lowland, in *Mikrofitofossilii i detal'naya stratigrafiya morskogo mezozoya i kainozoya Sibiri* (Microphytofossils and Detailed Stratigraphy of the Marine Mesozoic and Cenozoic of Siberia), Novosibirsk: Nauka, 1994, pp. 98–104.

Martini, E., Standard Tertiary and Quaternary Calcareous Nannoplankton Zonation, *Proc. II Plankt. Conf.*, Rome, 1970, pp. 730–785.

Meyen, S.V., *Vvedenie v teoriyu stratigrafii* (Introduction to the Theory of Stratigraphy), Moscow: Nauka, 1989.

Muzylev, N.G., *Stratigrafiya paleogena yuga SSSR po nannoplanktonu (Severnyi Kavkaz i Krym)* (Nannoplankton Paleogene Stratigraphy of the Southern USSR: Northern Caucasus and Crimea), Moscow: Nauka, 1980.

Okada, H. and Bukry, D., Supplementary Modification and Introduction of Code Numbers to the Low Latitude Coccolith Biostratigraphic Zonation, *Marine Micropaleontol.*, 1980, no. 5, pp. 321–325.

Panova, L. A. Palynostratigraphy of the Paleogene Sediments of the Caucasus, in *Palinologiya v SSSR* (Palynology in the USSR), Novosibirsk: Nauka, 1988, pp. 143–147.

Perch-Nielsen, R. and Saunders, J.B., Cenozoic Calcareous Nannofossils, in *Plankton Stratigraphy*, London: Cambridge Univ. Press, 1985, pp. 427–555.

Postanovleniya Mezhvedomstvennogo stratigraficheskogo komiteta (MSK) i ego postoyannykh komissii (Resolutions of the Interdepartmental Stratigraphic Committee (ISC) and Its Permanent Commissions), Leningrad: VSEGEI, 1989.

Prakticheskaya palinostratigrafiya (Practical Palynostratigraphy), Panova, L.A., Ed., Leningrad: Nedra, 1990.

Rubina, N.V. and Droznes, M.A., Eocene Sediments of the Lower Ob' River Region, in *Resheniya i trudy Mezhvedomstvennogo soveshchaniya po dorabotke i utochneniyu stratigraficheskikh skhem Zapadno-Sibirskoi nizmennosti* (Resolutions and Proceedings of the Interdepartmental Conference on the Elaboration and Specification of Stratigraphic Schemes of the West Siberian Lowland), Leningrad: Gostoptekhizdat, 1961, pp. 264–271.

Schrader, H.J. and Fenner, J., Cenozoic Diatom Biostratigraphy and Taxonomy, *Initial Rep. Deep Sea Drill. Proj.*, 1976, vol. 38, pp. 921–1099.

Steurbaut, E., New Early and Middle Eocene Calcareous Nannoplankton Events and Correlations in Middle to High

Latitudes of the Northern Hemisphere, *Newslett. Stratigr. Berlin*, 1988, vol. 18, no. 2, pp. 99–115.

Steurbaut, E. and Nolf, D., Revision of Ypresian Stratigraphy of Belgium and Northwestern France, *Meded. Werkgroep Tertiar. Kwartiare Geol.*, 1986, vol. 23, no. 4, pp. 115–172.

Stratigraficheskii kodeks SSSR (Stratigraphic Code of the USSR), Zhamoida, A.L, Ed., St. Petersburg: Mezh. Stratigr. Com., 1992.

Strel'nikova, N.I., *Paleogenovye diatomovye vodorosli* (Paleogene Diatoms), St. Petersburg: St.-Peterb. Gos. Univ., 1992.

The Northwestern European Tertiary Basin. Results of International Geological Correlation Programme Project N 124, *J. Geol.*, 1988, no. 100.

Vasil'eva, O.N., *Palinologiya i stratigrafiya morskikh otlozhenii paleogena Yuzhnogo Zaural'ya* (Palynology and Stratigraphy of Paleogene Marine Sediments from the Southern Transural Region), Sverdlovsk: Ural. Otd. Akad. Nauk, 1990.

Zonal'naya stratigrafiya fanerozoya SSSR (Phanerozoic Zonal Stratigraphy of the USSR), Moscow: Nedra, 1991.

Stratigraphy and Geological Correlation, Vol. 5, No. 4, 1997, pp. 353–361. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 4, 1997, pp. 46–54.
Original Russian Text Copyright © 1997 by Martynov, Gnibidenko, Nikitin.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

The Lower Miocene of the Tara–Irtysh Region: Stratigraphy, Paleobotany, Paleomagnetism

V. A. Martynov*, Z. N. Gnibidenko, and V. P. Nikitin***

** Novosibirsk Experimental-Methodical Expedition of the State Enterprise "Novosibirskgeologiya" Roskomnedra, ul. Potaninskaya 3a, Novosibirsk, 639099 Russia*

*** Institute of Geophysics, Siberian Division, Russian Academy of Sciences, Universitetskii prospekt 3, Novosibirsk, 630090 Russia*

Received August 23, 1995; in final form March 23, 1996

Abstract—The Tara–Irtysh region, located in the central part of West Siberia, is of interest because it represents the reference stratotype region for the elaboration of the Neogene stratigraphic scale. The stratigraphic research of continental Oligocene-Miocene deposits in the region is difficult because fragmentary sections here recorded a complex combination of lateral and vertical stratification. Previously, peculiar lithostratigraphic units (formations, beds) often bearing distinct paleofloral assemblages were traced in many borehole sections. These assemblages form a succession of floral levels, three of which—the Lyamin, Ekaterininskoe, and Vasyugan—probably correspond to the early Miocene. New multipurpose studies allowed paleobotanicalal data to be correlated with paleomagnetic data. Three magnetic polarity zones were distinguished in the combined section. The lower zone of reverse polarity is characterized by the Lyamin flora, the middle, zone of normal polarity, by the Ekaterininskoe flora, and the upper zone, of reverse polarity by the Vasyugan flora. Based on the correlation performed, we draw the conclusion that the magnetic polarity zones are of a regional extension and their geochronologic equivalents are correlative with epochs of the standard magnetochronologic scale. Thus, beds with the Ekaterininskoe flora that were correlated via auxiliary sections with the upper Baigubek Horizon of the Ustyurt–Aral region were accepted to be correlative with Epoch 21 and assigned to the Aquitanian Stage. The overlying beds with the Vasyugan flora are probably correlative with Epoch 20 (the lower Burdigalian), whereas the lowermost peculiar member of the section with the Lyamin flora can correspond to the lowermost Aquitanian–upper Chattian interval (Epochs 22 and, probably, 23).

Key words: *stratigraphy, paleocarpology, floral level, paleomagnetsm, magnetic polarity zone, Tara–Irtysh region, West Siberia*

The subdivision of the terrestrial Oligocene–Miocene deposits that are universally spread in West Siberia is of great importance because the available stratigraphic scales bear a series of certain assumptions. This is quite natural because sections of continental deposits show a complex combination of vertical stratification, with lateral changes related to long-term migrations of facies zones and particular facies (alluvial, lacustrine and palustrine). The studies and correlation of Neogene formations of Siberia long led scientists to conclude that they represent a combination of lateral, often multi-stage bedding (Martynov, 1969, 1980). The application of paleontological methods to study these deposits is limited by investigation of plant remains—fossil seeds and fruits, pollen and spores, and rare leaf imprints. To enhance the reliability of stratigraphic scales, other research methods should therefore be used, primarily the paleomagnetic method. Integration of a series of local sections in the Barabin plain and Irtysh region allows the elaboration of the Neogene magnetostratigraphic scale of West Siberia to be initiated (Gnibidenko *et al.*, 1989, 1991). The materials considered in this paper were collected during field work conducted recently in the Tara–Irtysh region, located in the central part of the West Siberia Lowland apart from its elevated fringing. This region is of importance because it represents the reference stratotype area for regional and correlation stratigraphic scales (the region comprises reference sections of the upper Oligocene Turtas Formation and the stratotype of the Miocene Abrosimovka Formation) and is promising in relation to zircon–ilmenite placers (Fig. 1).

In small outcrops in the Bol'shaya Abrosimovka River Valley, the right tributary of the Irtysh River (settlement of Ekaterininskoe), N.K. Vysotskii, P.L. Dravert, K.S. Afanas'ev, and M.D. Spiridonov sampled leaf imprints that were studied by Krishtofovich (1928) and, later by Krishtofovich and Borsuk (1939). These materials and coeval fossil plants sampled in the Ui and Shish river valleys represent the so-called Tara flora, which is considered to be the reference Miocene flora of West Siberia (Gorbunov, 1962). Abundant remains of fossil seeds and fruits from the same brown coal beds were also studied by P.A. Nikitin and later by Dorofeev (1957,

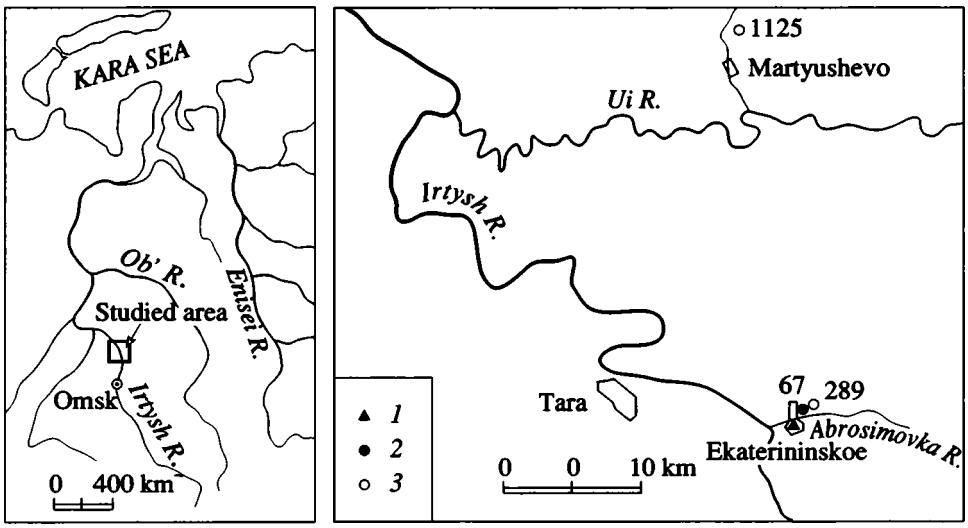


Fig. 1. Geographic localities of sections: (*1*) outcrop in the Bol'shaya Abrosimovka River valley; (*2*) stratotype of the Abrosimovka formation (Borehole 67); (*3*) additional boreholes.

1963) and Nikitin (1970). Thiese Tertiary coal-bearing deposits were named the Abrosimovka Formation after the locality of brown coal outcrops. It was established by detailed drilling that brown coal beds occur at different levels, and this name was therefore assigned to upper coal-bearing beds, which outcrop along the Bol'shaya Abrosimovka River (Gurari *et al.*, 1961). The section of Borehole 67 drilled close to the main occurrence of the Tara flora in the Katyushina Gorka Rise was suggested as the formation stratotype (Gorbunov and Vasil'ev, 1972). The borehole terminated in marine clays of the Tavda Formation (upper Eocene), which is successively overlain by the lower Oligocene Atlym and Novomikhailovka horizons, upper Oligocene Zhuravka Horizon, and Miocene coal-bearing Abrosimovka Horizon. Thus, this section is of reference importance owing to its completeness.

Despite the relatively rich material sampled in the area of the Abrosimovka Formation stratotype, the age of the related Tara flora was ambiguosly interpreted. Krishtofovich and Borsuk considered this flora to be the Miocene, and even the late Miocene in age, whereas Gorbunov, P.A. Nikitin, and V.P. Nikitin referred it to the early Miocene. Dorofeev, who for a long time dated the Tara flora as the Oligocene, later came to conclusion that "Tara floras, being of peculiar, Siberian appearance and having their own place in the general history of the Tertiary flora, resemble the Aquitanian–Burdigalian floras of Western Europe, which also show basic features inherited from the Oligocene flora and appearance of Miocene forms" (Dorofeev, 1965, p. 70). Finally, owing to comprehensive palynologic studies, spore–pollen assemblages of the Abrosimovka Formation were correlated with palynoassemblages from the upper Baigubek Horizon of the Ustyurt–Aral region (Boitsova and Panova, 1967; Panova, 1970), whose Aquitanian age was substantiated by finds of marine mollusks (Korobkov, 1974). Based on this correlation, the Abrosimovka Horizon with the Tara flora was placed in the lower Miocene (at the level of the Aquitanian Stage) in the correlation stratigraphic scale.

However, this correlation of distant sections is naturally conditional. Moreover, this is aggravated by the uncertain position of the upper Baigubek Horizon floras relative to the standard stratigraphic scale. For instance, in the opinion of Zhilin (1991), these floras are similar in their ecological type and composition to the reference Chattian floras from the lower Baigubek (Karatomak) Horizon. However, because of their higher position in the section and coexisting fauna (*Cerastoderma levinae* Beds), they are placed at the level of the Aquitanian Stage. According to Akhmet'ev (1991), coeval Aquitanian floras of the Aral and Turgai regions and comparable Ashutas floras of the Zaisan depression are most likely of the Chattian age. For West Siberia, the age determination of floras considered below is also difficult and requires further thorough studies and more reliable correlation between sections including those from the adjacent Turgai depression.

Based on comprehensive studies of the Abrosimovka Formation sections throughout the large territory, we came to the conclusion that they comprise strata of a somewhat different stratigraphic level, which is supported by peculiarities of fossil floras (Martynov, 1984; Nikitin, 1984).

It was shown previously that the thorough analysis of the taxonomic composition of particular Cenozoic floras of Siberia, the geological structure of their distribution areas and litho- and biostratigraphic correlation of sections make it possible to construct a peculiar "ladder," every step of which (not always of equal height) bears sufficiently distinct paleobotanicalal characteris-

tics and forms so-called floral levels (Nikitin, 1984, 1988).

Representing short stages in the evolution of West Siberian flora and vegetation, these floral levels can be simultaneously considered as regional stratigraphic units subordinate to the horizon and thus corresponding to beds with geographic names (*Stratigraficheskii kodeks*, 1992, item IV.7). For instance, the Lagernyi Sad flora that characterizes probably the phase of the maximum flourishing of temperate thermophilic to mesophilic Turgai forests corresponds to the Zhuravka geohistorical stage of the late Oligocene.

The older Basandai and somewhat younger Koshkul' floral levels can be distinguished within this stage. The Tara–Vasyugan flora (the Abrosimovka Horizon) comprises the Lyamin, Ekaterinskoe, Vasyugan, and Kireevskoe levels whose seed assemblages reflect progressive impoverishment of the coniferous–broad-leaved vegetation, which represented the basis of the Turgai flora, along with a gradual increase of the share of the mesophilic herbage and similarly gradual degradation of forest landscapes into forest–steppe areas. Floral levels are also distinguished within older early Oligocene floras, as well as within younger late Miocene and Pliocene floras.

The very peculiar seed assemblage from brown-coal beds in the vicinity of Ekaterininskoe Settlement exemplifies the type flora of the Ekaterininskoe level (Ekaterininskoe Beds). In the reference section of Borehole 67, the Ekaterinskoe Beds are underlain by a uniform member of thin-layered sandy–silty–clayey rocks differing in color and structural features from clayey coal-bearing deposits and separated from them by a 90-cm-thick bed of clayey pebblestone or conglomerate (44.8–45.7 m). This peculiar gray-colored member in the interval of 45.7–68.0 m was referred by the authors of the stratotype to the Turtas Formation, though they themselves noted that bluish-greenish gray clayey–silty rocks characteristic of the latter occur lower in the section (68.0–75.3 m). The upper half of this gray-colored member incorporates interbeds with fine plant detritus (interval of 50.0–54.5 m) and rich seed assemblages, which have a more archaic appearance than those from the Ekaterininskoe Horizon (the Lyamin floral level—see below).

Following the recommendation of the Neogene Commission of the Interdepartmental Stratigraphic Committee to cross the Oligocene–Miocene boundary, Borehole 289 was drilled in close vicinity to the stratotype borehole, and lithologic, paleocarpologic, palynologic, logging, and paleomagnetic investigations were performed here (Fig. 2). This borehole penetrated to a depth of 120.5 m and terminated in lower Oligocene deposits of the Novomikhailovka Formation, which is crowned by a brown-coal bed. This is overlain in the interval of 86.4–75.3 m by bluish-greenish gray aleuropelites with fine intercalations of powdery silt that are typical of the Turtas Formation. Upsection to the depth of 48.8 m, like in Borehole 67, a member of finely interlayering brownish gray silty–sandy clays, greenish gray silt, and fine-grained sands occurs, and sandy beds are locally saturated with fine plant detritus. The base of the member is represented by a bed of variably grained quartz sand with small-sized gravel and clayey pellets, which marks the contact between the Turtas Formation and the overlying member. The core from the interval of 48.8–37.4 m is composed of dense brownish and brown-gray clays with plant detritus and large wood fragments; the brown-coal bed occurs near the base. Upsection (interval of 37.4–30.0 m), the clayey member is overlain by a member composed of brownish gray sand with clayey interbeds of similar color also bearing plant detritus. It is interesting that in this section, similar to Borehole 67, deposits of an extensive freshwater basin (*lake or sea*) corresponding to the Turtas Formation have a reduced thickness (11 m versus 30–40 m in neighboring sections). This is explained by either the erosion of the formation upper layers, or their facial gradation into deposits, that underlie the coal-bearing member.

Two samples of gray fine-grained quartz sands with plant detritus (depths of 72.1 and 64.3 m) yielded two diverse (132 and 90 species, respectively) and interesting seed assemblages. Though retaining distinct features inherited from older floras of the Zhuravka Horizon (the Koksul' level), these assemblages include many archaic forms of the Oligocene appearance. These are *Scirpus decipiens* V. Nikit., *Morus sibirica* Dorof., *Urticicarpum oligocenum* Dorof., *Nymphea macrosperma* V. Nikit., *Tavdenia* sp., *Ranunculus priscus* V. Nikit., and others.

Simultaneously, these assemblages mark the appearance of a large group of young, mainly Miocene plants unknown in typical Oligocene floras, such as *Stratiotes sibiricus* Dorof., *Carex flagellata* C. et E. Reid, *Alnus* aff. *torulosa* Dorof., *Betula* cf. *uralensis* Dorof., *Tubela* cf. *omskiana* Dorof., *T.* cf. *rossica* Dorof., *Macleaya sibirica* V. Nikit., *Ajuga gorbunovii* V. Nikit., and others. As was previously noted, equally diverse assemblages of a similar type were collected earlier when studying cores from Borehole 67 (under coaliferous member, depth interval of 50.0–54.5 m). Floras from both boreholes are considered to be characteristic of the Lyamin floral level (Nikitin, 1989).

Spore–pollen spectra from Borehole 289 (interval of 62.7–66.0 m) investigated by V.V. Landysheva also show a peculiar composition: a significant share among coniferous pollen (the average content of 32–42%) belongs to the Taxodiaceae family, (up to 11%), whereas, among phanerogamous pollen, the broad-leaved forms prevail over small-leaved plants, which is typical of the late Oligocene assemblages. Simultaneously, unlike in spectra from underlying deposits of the Turtas Formation (76 m and deeper), this assemblage shows the increased role of herbaceous pollen, particularly that of aqueous forms and herbage.

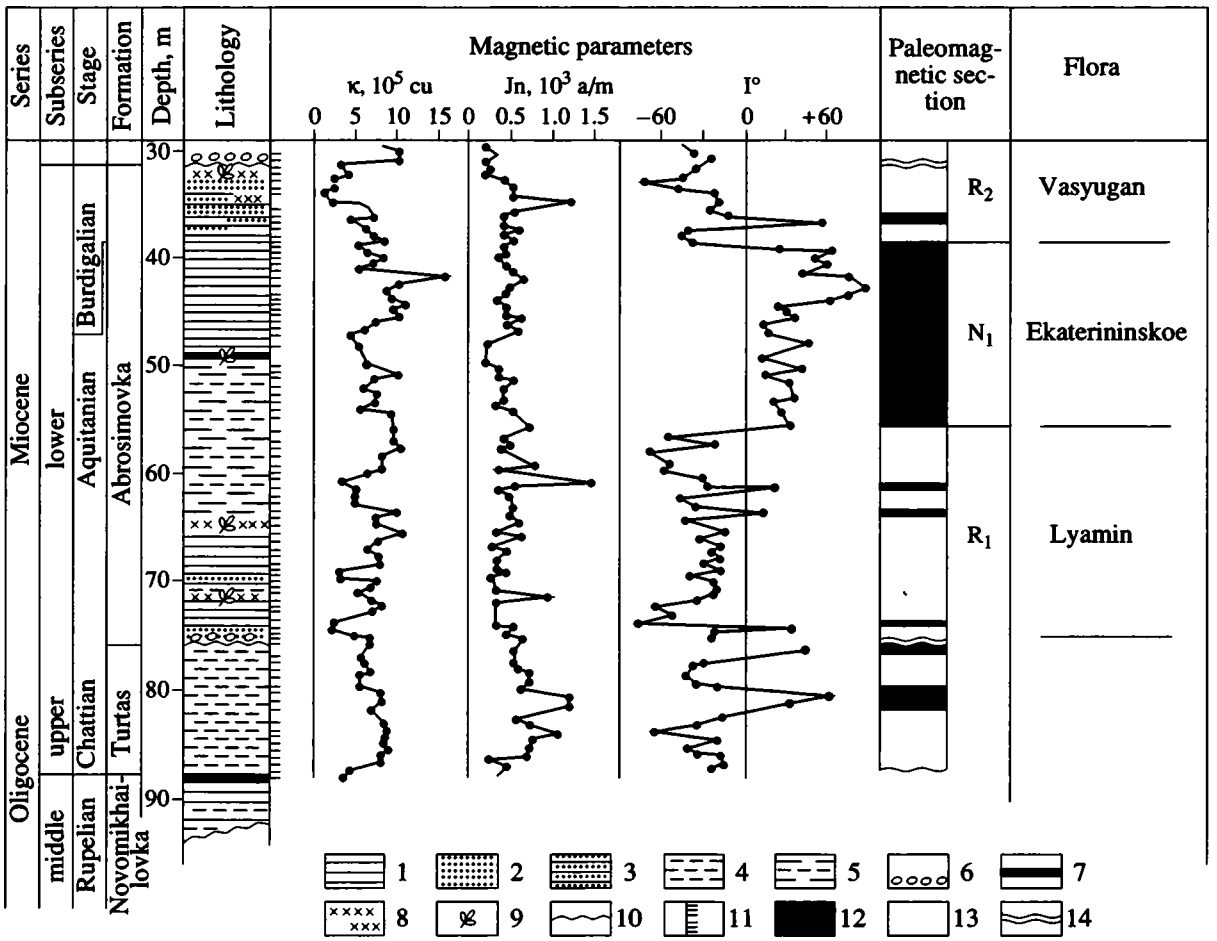


Fig. 2. Lithostratigraphic and magnetostratigraphic sections of Borehole 289: (1) clay; (2) sand; (3) fine interlayering of clay and sand; (4) silt; (5) interlayering of silty clay and silt; (6) gravel, small pebble; (7) brown coal; (8) plant detritus; (9) beds with flora; (10) erosion surface; (11) oriented samples point no.; intensity of magnetization (12) normal polarity; (13) reverse polarity; (14) probable hiatus in the sequence of paleomagnetic stet.

Thus, the paleobotanical data in total shows that the intervals under coaliferous deposits (beds with the Lyamin flora) are equally close to both the Oligocene (the Zhuravka Horizon) and lower Miocene and probably can represent the boundary strata. The clay sample from the brown-coal member (interval of 48.8–37.4 m) collected in the depth interval of 47.7–48.1 m from beds, whose appearance and position in the section are similar to those of coal measures outcropping in the Bol'shaya Abrosimovka River Valley (the main occurrence of the Tara flora), yielded a seed assemblage virtually identical to the type flora of the Ekaterininskoe level. Unlike the above-considered Lyamin assemblages, this one lacks the Paleogene *Scirpus decipiens* and other archaic forms. Unfortunately, the Ekaterininskoe assemblage from Borehole 289 is relatively impoverished (46 taxons); nevertheless, it is sufficiently distinct, and, thus, correspondence of this section to the stratotype is doubtless. The palynoassemblage in two samples from the interval of 46–47 m is also generally similar to the assemblage from flora-bearing beds in the Abrosimovka River valley established previously (Merkulova, 1966).

Unfortunately, the fossil seed flora from the interval of 32.0–32.3 m is poor (ten species) and, thus, stratigraphically insignificant. The palynoassemblage from the depth of 32.5 m clearly differs from older floras in the increased share of *Sphagnum* and Polypodiaceae spores and herbaceous pollen, whereas the content of Taxodiaceae and broad-leaved pollen remains high (21.6 and 11.6%, respectively), which is generally characteristic of the upper part of the Abrosimovka Horizon.

Paleomagnetic study of the core from Borehole 289 is the first one conducted in the Tara–Irtysh region. It showed that the rock member in the interval of 48.8–75.3 m, whose lower half (up to the depth of 57.0 m) bears the seed assemblages of the Lyamin floral level, has reverse polarity and corresponds to magnetic polarity zone R_1 (Fig. 2). The higher coal-bearing clayey

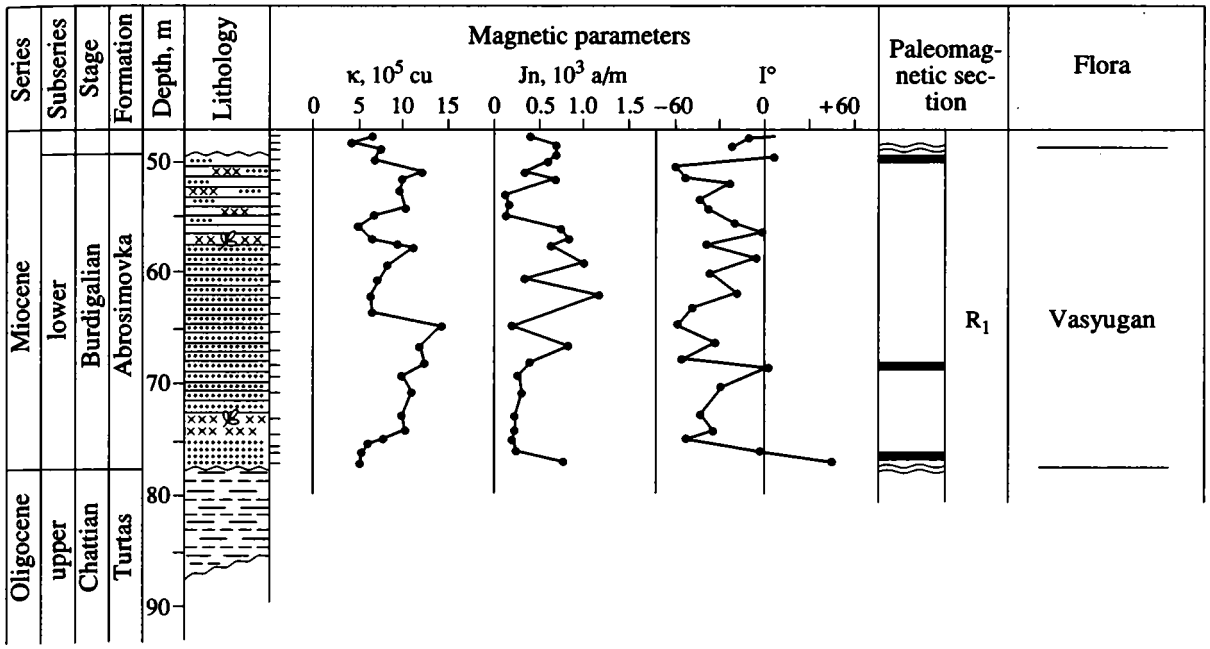


Fig. 3. Litho-and magnetostratigrapihy of Borehole 1125: (for symbols see Fig. 2).

member (interval of 37.4–48.8 m) falls within the normal polarity zone (magnetic polarity zone N_1, interval of 40.0–57.0 m), whereas overlying, mainly sandy beds (interval of 30.0–37.4 m) show the reverse polarity (magnetic polarity zone R_2).

Paleomagnetic parameters were also studied in the section outcropping near the settlement of Ekaterininskoe in the Bol'shaya Abrosimovka River Valley and bearing plant remains analyzed by Krishtofovich. The clayey member with brown-coal beds 2.5 m thick, which yielded the seed assemblage of the Ekaterininskoe level, shows the normal polarity and corresponds to magnetic polarity zone N_1 (Fig. 4).

The stratigraphic section near the settlement of Ekaterininskoe is supplemented by the section drilled (Borehole 1125) in the Tara area of the Ui River basin, the right tributary of the Irtysh River, 5 km north-northeast of the settlement of Martyushevo. The Turtas Formation,whose total thickness makes up about 30 m, is here overlain in the interval of 76.7–48.9 m by a member of interlayering brownish silty clay, brownish and brown clayey silt, and fine-grained sand with accumulations of plant detritus; by lithology, the member was referred to the Abrosimovka Formation (Figs. 3, 4).

Paleocarpological analysis of two cores from Borehole 1125 sampled in the interval of 73.0–74.0 m and at the depth of 57.0 m yielded diverse seed assemblages (96 and 72 species, respectively) that are distinctly younger as compared with that from the Ekaterininskoe stratotype. This level is marked by the first appearance of many young plant species whose flourishing stage was in the Miocene or even in the Pliocene (true *Caldesia cylindrica* Dorof., *Sparganium juzepczukanium* Dorof., characteristic species of the *Scirpus* genus, *Epipremnum crassum* C. et E. Reid, *Myriophyllum pulchellum* Dorof., *Melastomites vera* V. Nikit., *Teucrium elongatum* Dorof.) These species appear against the background of dominant transitional Oligocene–Miocene forms including some archaic species more typical of the late Oligocene–early Miocene assemblages (*Caldesia* cf. *proventitia* Nikit., cf. *Braseniella* sp., *Ailanthus tertiaria* Dorof., and some others).

A remarkable feature of this fossil flora is a relative decrease in arboreal plant remains. Whereas in the assemblages of the Lyamin and Ekaterininskoe levels in Borehole 289 the share of tree plants, shrubs, and lianas makes up 25 to 35% of the total composition, the share of these forms in the assemblages from Borehole 1125 does not exceed 14–17%. All these features are typical of the Vasyugan floral level that is substantiated by fossil seed assemblages from outcrops in the Vasyugan River sides (Gorbunov *et al.*, 1970; Nikitin, 1988). Palynospectra obtained by V.B. Landysheva from Borehole 1125 (interval of 52.8–68.2 m) sharply differ from those in the Turtas Formation, whose top in the borehole section is located at the depth of 76.7 m. They are marked by a sharp, step-like decrease in the content of coniferous pollen from 35–60 to 22–31%. Simultaneously, this flora shows an increased share of pollen of small-leaved plants, such as alder, birch, and willow among phanerogamous plants (16–28% versus 3–14% in the Turtas Formation), a higher abundance of grass and shrub pollen (16–27 versus 2–5%) and a decreased content of pollen of broad-leaved trees and

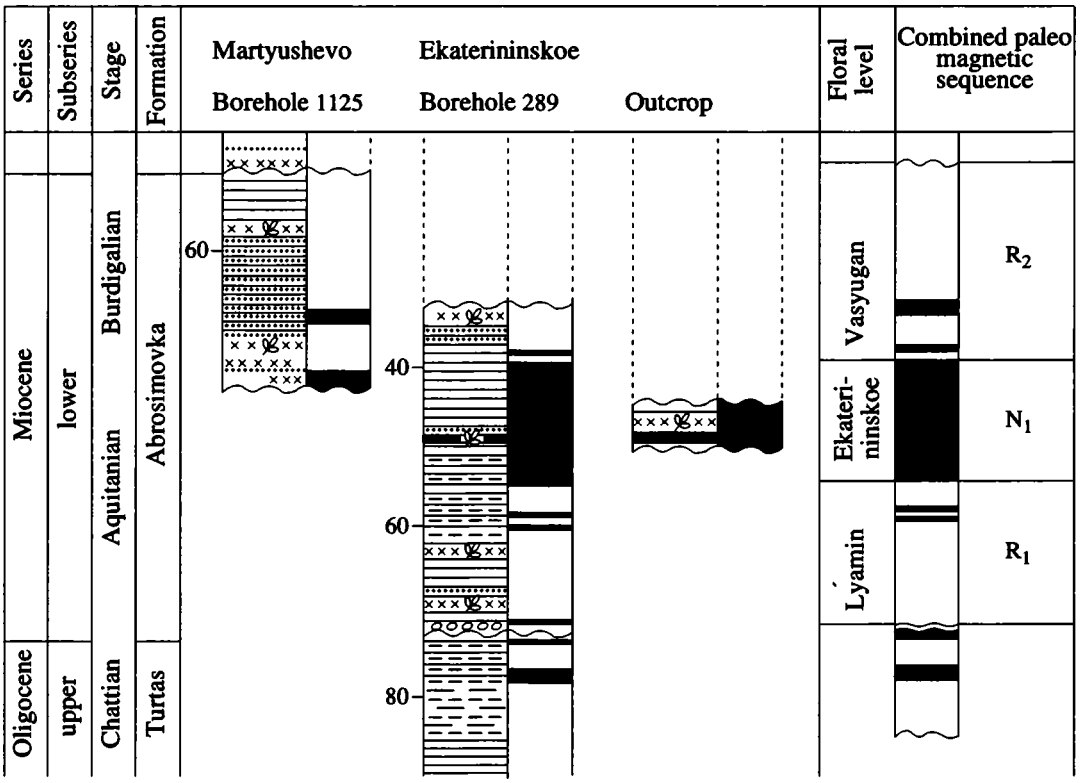


Fig. 4. Combined magnetostratigraphic section of the lower Miocene deposits of the Tara–Irtysh region (for symbols see Fig. 2).

other thermophylic plants (11–16 versus 20–4%). It should be emphasized that these palynospectra distinctly differ from spore–pollen assemblages in the layers of the Abrosimovka Formation, which contain the Tara flora and Ekaterininskoe seed assemblages (Boreholes 67, 289, and natural outcrops of brown coal in the Abrosimovka River Valley). They are to a certain degree similar to palynospectra of the Beshcheul Formation and probably reflect the next, post-Ekaterininskoe stage in the evolution of the Miocene flora of West Siberia. Thus, judging from the whole set of paleobotanical data, the section of Borehole 1125 shows an unconformity between the upper Oligocene deposits of the Turtas Formation and the overlying upper beds of the Abrosimovka Formation (interval of 76.7–48.9 m). The entire 28-m-thick sequence recovered here corresponds to the reverse polarity zone (Fig. 3). This zone may also include reversely magnetized beds with poor paleontologic characteristics recovered from Borehole 289 and directly overlying normally magnetized coal-bearing clays of the Abrosimovka Formation (magnetic polarity zone R_2, Figs. 2, 4).

Figures 2, 3, and 4 demonstrate paleomagnetic characteristics of the sections under study. Their correlation, taking into account the stratigraphic succession of the established floral levels, allowed us to compile a combined 20–28-m-thick magnitostratigraphic section (Fig. 4) that includes three major magnetic zones with normal and reverse polarity—R_1, N_1, and R_2. Narrow (up to 1 m) subzones of normal polarity are recorded within the magnetic polarity zones R_1 and R_2. The 20-m-thick deposits corresponding to the lower reversely magnetized zone R_1 are characterized by flora of the Lyamin level (Figs. 2, 4). Sediments of the overlying, normally magnetized zone N_1 (20 m thick) contain flora of the Ekaterininskoe level (Figs. 2, 4), whereas the magnetic polarity zone R_2 (8 and 28 m thick in Boreholes 289 and 1125, respectively) is characterized by the Vasyugan flora (Figs. 2–4).

It should be kept in mind, however, that these sections of continental deposits display discrete sedimentation patterns that are expressed in their layered structures and alternation of sediments with different granulometric characteristics. Therefore, the established succession of lithologic members may not adequately reflect the duration of their formation and, thus, the detailed correlation of defined local magnetic polarity zones with the standard magnetostratigraphic scale may be reliably performed only through the integration of several sections.

It was shown above that beds with the Ekaterininskoe flora correlative via intermediate sections with the Upper Baigubek Horizon, whose age is substantiated by faunal remains, may be referred to the Aquitanian Stage. This is supported by the normal magnetic polarity of both the Ekaterininskoe beds (our data) and the

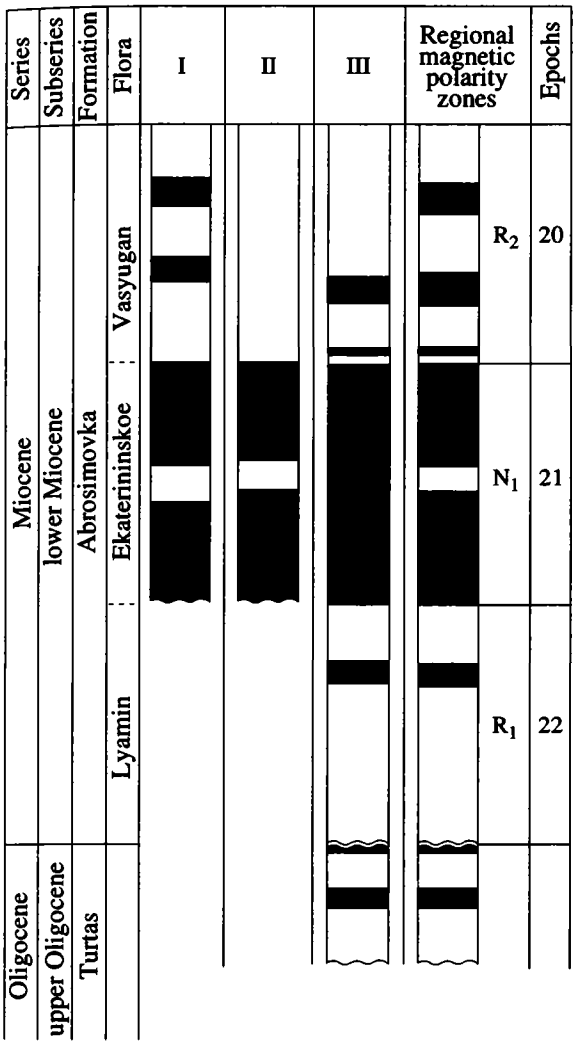


Fig. 5. Magnetostratigraphic correlation of the lower Miocene deposits the Tara–Irtysh region (for symbols see Fig. 2). Sections: (I) Barabin plain; (II) Omsk–Irtysh region; (III) Tara–Irtysh region.

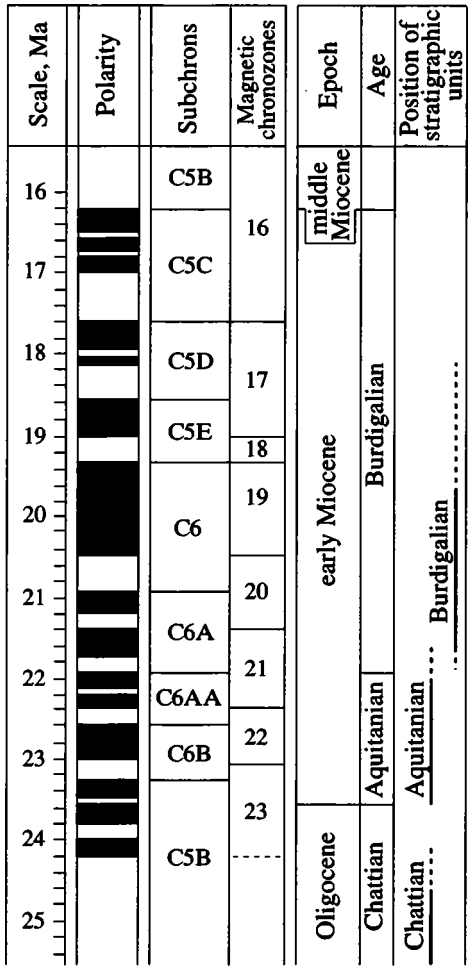


Fig. 6. The late Oligocene–early Miocene interval of the geochronologic scale (Berggren *et al.*, 1985; *Stratigraphy ...*, 1991).

upper Baigubek Horizon of the northern Ustyurt [data on the Kintykche reference section of Kazanskii (1990) and Kunaev (1990)]. Results of the previous magnetostratigraphic studies of Neogene deposits of southern West Siberia (Gnibidenko *et al.*, 1989, 1991) and recently obtained data allow us to assume that geochronologic equivalents of regional magnetic polarity zones defined in the reference section (Fig. 5) are correlative with epochs of the standard magnetostratigraphic scale of the Neogene (Berggren *et al.*, 1985). In this case, the magnetic polarity zone N_1 bearing the seed assemblages of the Ekaterininskoe level correlates to Chron 21 (parts of Subchrons C6AA–C6A) of the magnetochronologic scale (Berggren *et al.*, 1985; *Stratigraphy...*, 1991). The underlying magnetic zone R_1 with the Lyamin flora corresponds to Chron 22 (Subchron C6B and part of Subchron C6AA) and overlying magnetic polarity zone R_2 characterized by the Vasyugan assemblages, to Chron 20 (parts of Subchrons C6A and C6). Similar conclusions were drawn previously when we correlated the combined magnetostratigraphic section of southern West Siberia with the Neogene scale of the Mediterranean and its paleomagnetic characteristics (Gnibidenko and Martynov, 1990). The time interval of Chrons 22–20 is determined to be approximately 23.4–20.5 Ma, whereas the Aquitanian Age, according to Berggren's scale, spans from 23.7 to 21.8 Ma. Consequently, deposits with the Ekaterininskoe and Lyamin floras correspond to the Aquitanian, whereas the Vasyugan beds can be correlated with the lowermost Burdigalian. Figure 5 demonstrates the suggested scheme of correlation of the lower Miocene deposits in West Siberia.

Nevertheless, it should be noted that age differences between floras from the Lyamin and Vasyugan levels are probably of higher rank than a stage. Judging from

the evolution rates of flora and vegetation of the Tara–Irtysh region, it can be assumed that the Ekaterininskoe Beds with complex structure could be correlated with the Aquitanian Stage as a whole, beds with the Lyamin flora, with the Chattian–lowermost Aquitanian interval (Epoch 23, Subchron C6C), and beds with the Vasyugan flora, as was noted above, with the Burdigalian Stage.

The suggested correlation between defined regional magnetic polarity zones and units of the standard scale can be improved in the course of further multidisciplinary investigations.

ACKNOWLEDGMENTS

The work was performed following the recommendations of the Neogene Commission of the Interdepartmental Stratigraphic Committee and owing to the support of the Russian Foundation for Basic Research (project no. 95-05-15599).

Reviewer M.A. Akhmet'ev

REFERENCES

Akhmet'ev, M.A., Comparison of the Early Oligocene Kiin-Kerish Flora with Other Paleogene Floras, in *Formirovanie eotsen–miotsenovoi flory Kazakhstana i Russkoi ravniny. Krishtofovicheskie chteniya: Vyp. 2* (Formation of the Eocene–Miocene Flora of Kazakhstan and Russian Plain. Krishtofovich Memorial Conference: Issue 2), Leningrad: Nauka, 1991, pp. 37–56.

Berggren, W.A., Kent, D.V., Flynn, J.J., *et al.*, Cenozoic Chronology, *Bull. Geol. Soc. Am.*, 1985, vol. 96, no. 11, pp. 1407–1418.

Boitsova, E.P. and Panova, L.A., Spore and Pollen Assemblages from Paleogene and Neogene Continental Deposits of West Siberian Lowland and Kazakhstan, in *Stratigrafiya i paleontologiya mezozoiskikh i paleogen–neogenovykh kontinental'nykh otlozhenii aziatskoi chasti SSSR* (Stratigraphy and Paleontology of Mezosoic and Paleogene–Neogene Continental Deposits in the Asian Part of the USSR), Leningrad: Nauka, 1967, pp. 262–270.

Dorofeev, P.I., Materials for the Study of the West Siberia Tertiary Flora, in *Sbornik pamyati A.N. Krishtofovicha* (Papers in Memory of A.N. Krishtofovich), Moscow: Akad. Nauk SSSR, 1957, pp. 277–312.

Dorofeev, P.I., *Tretichnye flory Zapadnoi Sibiri* (Tertiary Floras of West Siberia), Moscow: Akad. Nauk SSSR, 1963.

Dorofeev, P.I., Abstracts of Papers, *Mezhved. soveshchanie po Kontinental'nym otlozheniyam Azii* (Interdepartmental Conference on Continental Depozits in Asia), Leningrad, 1965, pp. 69–71.

Gnibidenko, Z.N. and Martynov, V.A., Magnetostratigraphic Correlation of Neogene Deposits of West Siberia and Mediterranean, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1990, no. 12, pp. 83–88.

Gnibidenko, Z.N., Martynov, V.A., Donchenko, V.V., *et al.*, Magnetostratigraphic Sequence of Neogene Deposits in the Barabin Depression, *Geol. Geofiz.*, 1989, no. 2, pp. 11–20.

Gnibidenko, Z.N., Martynov, V.A., Donchenko, V.V., *et al.*, Reference Section and Magnetostratigraphy of Neogene Deposits in the Omsk–Irtysh Region, *Geol. Geofiz.*, 1991, no. 1, pp. 71–78.

Gorbunov, M.G., Development of the Tertiary Flora in West Siberia (According to Data on Leaf Remains), in *Biostratigrafiya mezozoiskikh i tretichnykh otlozhenii Zapadnoi Sibiri* (Mesozoic and Tertiary Biostratigraphy of West Siberia), Leningrad: Gostoptekhizdat, 1962, pp. 312–327.

Gorbunov, M.G. and Vasil'ev, I.P., On the Stratigraphic Position of the Tertiary Flora in the Abrosimovka River Valley near the Mt., Tara the Irtysh River, Basin, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1972, no. 2, pp. 126–134.

Gorbunov, M.G., Gurari, F.G., Nikitin, V.P., *et al.*, New Data on Tertiary Stratigraphy of West Siberia Lowland, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1970, no 2, pp. 141–145.

Gurari, F.G., Shatskii, S.B. Khokhlova, G.Ya., *et al.*, Stratigraphy of Upper Paleogene Continental Deposits of the West Siberian Lowland, *Resheniya i trudy mezhvedomstvennogo soveshchaniya po dorabotke i utochneniyu stratigraficheskikh skhem Zapadno-Sibirskoi nizmennosti* (Resolutions and Proceedings of the Interdepartmental Meeting on Improvement and Refinement of Stratigraphic Schemes of the West Siberian Lowland), Leningrad: Gostoptekhizdat, 1961, pp. 303–313.

Kazanskii, A.Yu., Magnetostratigraphic Sequence of Upper Oligocene and Lower Miocene in the Northeastern Ustyurt, *Dokl. Akad. Nauk SSSR*, 1990, vol. 310, no. 4, pp. 935–938.

Korobkov, A.I., Chattian and Aquitanian Stages, and the Lower Neogene Boundary in the Territory of the USSR, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1974, no. 8, pp. 98–104.

Krishtofovich, A.N., New Data on the Upper Tertiary Flora of Northwestern Siberia, *Izv. Geol. Komiteta*, 1928, vol. 47, no. 7, pp. 751–757.

Krishtofovich, A.N. and Borsuk, M.I., Miocene Plants from the Irtysh River Near Tara Mt., the West Siberia, in *Problemy paleontolologii* (Problems of Paleontology), Moscow: Mosk. Gos. Univ., 1939, vol. 5, pp. 376–396.

Kunaev, M.S., Paleomagnetism of Eocene–Oligocene Deposits of the Northeastern Turan Plarform, *Cand. (Geol.–Mineral.) Dissertation*, Alma Ata: Institute of Geosciences, 1990.

Martynov, V.A., Peculiarities in the Stratigraphic Subdivision of Continental Deposits, in *Problemy stratigrafii* (Problems of Stratigraphy), Novosibirsk: Sib. Nauchno.–Issled. Inst. Geol. Geofiz. Mineral. Syr'ya, 1969, pp. 150–155.

Martynov, V.A., Local and Regional Stratigraphic Cenozoic Units of the West Siberian Platform, in *Problemy stratigrafii Sibiri v svete novykh dannykh* (Problems of Stratigraphy of Siberia in the Light of New Data), Novosibirsk: Sib. Nauchno.–Issled. Inst. Geol. Geofiz. Mineral. Syr'ya, 1980, pp. 79–99.

Martynov, V.A., Environments and Geological Boundaries in the Neogene of West Siberia, in *Sreda i zhizn' na rubezhakh epokh kainozoiya v Sibiri i na Dal'nem Vostoke* (Environments and Life at the Boundaries between Cenozoic Epochs in Siberia and the Far East), Novosibirsk: Nauka, 1984, pp. 151–157.

Merkulova, K.A., The Age of the Tara Flora (by Spore–Pollen Data), in *Palinologiya Sibiri* (Palynology of Siberia), Moscow: Nauka, 1966, pp. 90–95.

Nikitin, V.P., An Essay on Neogene Seed Floras of West Siberia, in *Resheniya i trudy mezhvedomstvennogo soveshchaniya po dorabotke i utochneniyu unifitsirovannykh i*

korrelyatsionnykh stratigraficheskikh skhem Zapadno-Sibirskoi nizmennosti: Chast' 2 (Resolutions and Proceedings of the Interdepartmental Meeting on Improvement and Refinement of Unified and Correlation Stratigraphic Schemes of the West Siberian Lowland: Part 2), Tyumen': Zap.-Sib. Nauchno-Issled. Inst. Geol. Geofiz. i Mineral. Syr'ya, 1970, pp. 244–258.

Nikitin, V.P., Miocene Floras of West Siberia, in *Sreda i zhizn' na rubezhakh epokh kainozoiya v Sibiri i na Dal'nem Vostoke* (Environments and Life at the Boundaries between Cenozoic Epochs in Siberia and the Far East), Novosibirsk: Nauka, 1984, pp. 146–151.

Nikitin, V.P., Neogene Floral Levels in West Siberia, in *Geologiya i poleznye iskopaemye yuga Zapadnoi Sibiri* (Geology and Mineral Resources of Southern West Siberia), Novosibirsk: Nauka, 1989, pp. 26–31.

Nikitin, V.P., Oligocene Floras of West Siberia (Based on Carpologic Investigations), in *Kainozoi Sibiri i Severo-Vostoka SSSR* (Cenozoic of Siberia and Northeastern USSR), Moscow: Nauka, 1989, pp. 26–31.

Panova, L.A., Paleogene Spore and Pollen Assemblages of the Southern and Central West Siberian Lowland, in *Resheniya i trudy mezhvedomstvennogo soveshchaniya po dorabotke i utochneniyu unifitsirovannykh i korrelyatsionnykh stratigraficheskikh skhem Zapadno-Sibirskoi nizmennosti. Chast' 2* (Resolutions and Proceedings of the Interdepartmental Meeting on Improvement and Refinement of Unified and Correlation Stratigraphic Schemes of the West Siberian Lowland. Pt. 2), Tyumen': Zap.-Sib. Nauchno-Issled. Inst. Geol. Geofiz. i Mineral. Syr'ya, 1970, pp. 121–132.

Stratigraficheskii kodeks (The Stratigraphic Code), St. Petersburg: Vsesoyuz. Geol. Inst., 1992.

Stratigraphy and Geologic History of the Cenozoic of Japan, Rept. Geol. Surv. Japan, 1991, no. 274, pp. 1–38.

Zhilin, S.G., Methodical Aspects of Paleofloral Investigations (the Kazakhstan Eocene–Miocene Floras as an Example), in *Formirovanie eotsenovo-miotsenovoi flory Kazakhstana i Russkoi ravniny. Krishtofovicheskie chteniya. Vyp. 2* (Formation of the Eocene–Miocene Flora of Kazakhstan and Russian Plain. Krishtofovich Memorial Conference. Issue 2), Leningrad: Nauka, 1991, pp. 57–88.

Stratigraphy and Geological Correlation, Vol. 5, No. 4, 1997, pp. 362–374. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 4, 1997, pp. 55–67.
Original Russian Text Copyright © 1997 by Devyatkin, Dodonov, Sharkov, Zykin, Simakova, Khatib, Nseir.
English Translation Copyright © 1997 by MAIK Nauka/Interperiodica Publishing (Russia).

The El-Ghab Rift Depression in Syria: Its Structure, Stratigraphy, and History of Development

E. V. Devyatkin*, A. E. Dodonov*, E. V. Sharkov, V. S. Zykin***, A. N. Simakova*, K. Khatib****, and H. Nseir******

** Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia*
*** Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences, Staromonetnyi per. 35, 109017 Russia*
**** Institute of Geology and Geophysics, Siberian Division, Russian Academy of Sciences, Universitetskii pr. 3, Novosibirsk, 630090 Russia*
***** General Administration of Geology and Mineral Resources, Damascus, Syria*

Received November 7, 1995

Abstract—The inner structure of the El-Ghab rift depression in Syria is analyzed for the first time using the drilling and geophysical data and the stratigraphy of its continental deposits, and their correlation with the K–Ar dated basalts is considered. The central part of the depression is formed as a graben filled with mainly lacustrine sediments whose thickness is up to 1000 m. The upper part of the sequence contains freshwater molluscan fauna. The time of formation of lacustrine beds, as determined from faunal evidence and K–Ar datings, is not earlier than the early Pleistocene. Three stages are distinguished in the development of the structure: (1) the prerift stage (Paleogene–early Miocene), (2) the anterift stage (late Miocene), and (3) the rift stage (Pliocene–Quarternary).

Key words: *stratigraphy, correlation, graben, rift, magmatism, transgression*

THE GEOLOGICAL POSITION AND STRUCTURE OF THE EL-GHAB DEPRESSION

The El-Ghab rift depression (graben) forms the northern end of the Levant rift belt that stretches meridionally from the Dead Sea depression to the border with Turkey (Fig. 1). Here the belt joins the East Anatolia fault zone. The geomorphological structure of the rift depression is described in a number of papers (Van Liere, 1960–1961; Ponikarov *et al.*, 1969; Trifonov *et al.*, 1991; Besancon and Sanlaville, 1993; Domas, 1994; Kopp *et al.*, 1994; Kopp, 1995). The central part of the depression is a plain covered on the surface with a thin bed of Pleistocene and Holocene sediments, which overlie the lacustrine Pliocene deposits several hundreds meters thick. The flanks of the depression are clearly limited by faults with a series of blocks and scarps, along which the central part of the graben is thrown down. The largest vertical displacement amplitudes (up to 2000–2500 m), as shown by drilling and geophysical data (Figs. 2, 3), were observed along the central part of the western flank. In this zone, the hypsometric marks of the surface of the Coastal Mountains rising above the depression reach 1500 m, whereas the surface of the depression near the fault is at a level of 600–700 m. The amplitudes of the vertical displacements along the eastern flank are less and reach 1000–1500 m. The recent faults in this area are more clearly manifested and lack the covering layer of avalanche–proluvial (olisthostrome) deposits typical of the western flank. In the south, the El-Ghab depression joins the narrow Massif graben, which has a prominently lifted western flank; further south, the depression merges with the Lebanese–Syrian strike-slip fault. In the north, the depression is divided by the Jebel Oustani horst anticline into two grabens.

Until recently, the inner structure of the El-Ghab depression remained almost unknown. At the end of the 1970s, scientists from the "Gruzgiprovodkhoz" (Water Resources Management Institution, Georgia) have obtained a certain amount of data from drilling and geophysical research, and our analysis of these materials allowed us to draw four principal transversal profiles and a structural scheme of the depression (Figs. 2 and 3). The distinct (up to 800-m deep) and very narrow fault-related troughs, which are divided in the central and northern parts of the depression by a longitudinal uplift, stretch along the western and eastern flanks of the El-Ghab depression. These troughs have steep sides of the fault type, and the vertical displacements occurred along them in the Pliocene–Pleistocene and, probably, in the Holocene as well. Particularly indicative in this respect is the eastern wall, where the faults rupture the Pliocene lacustrine sediments and basalt beds and lift them over the bottom of the depression in the shape of narrow, meridionally elongated stepwise blocks.

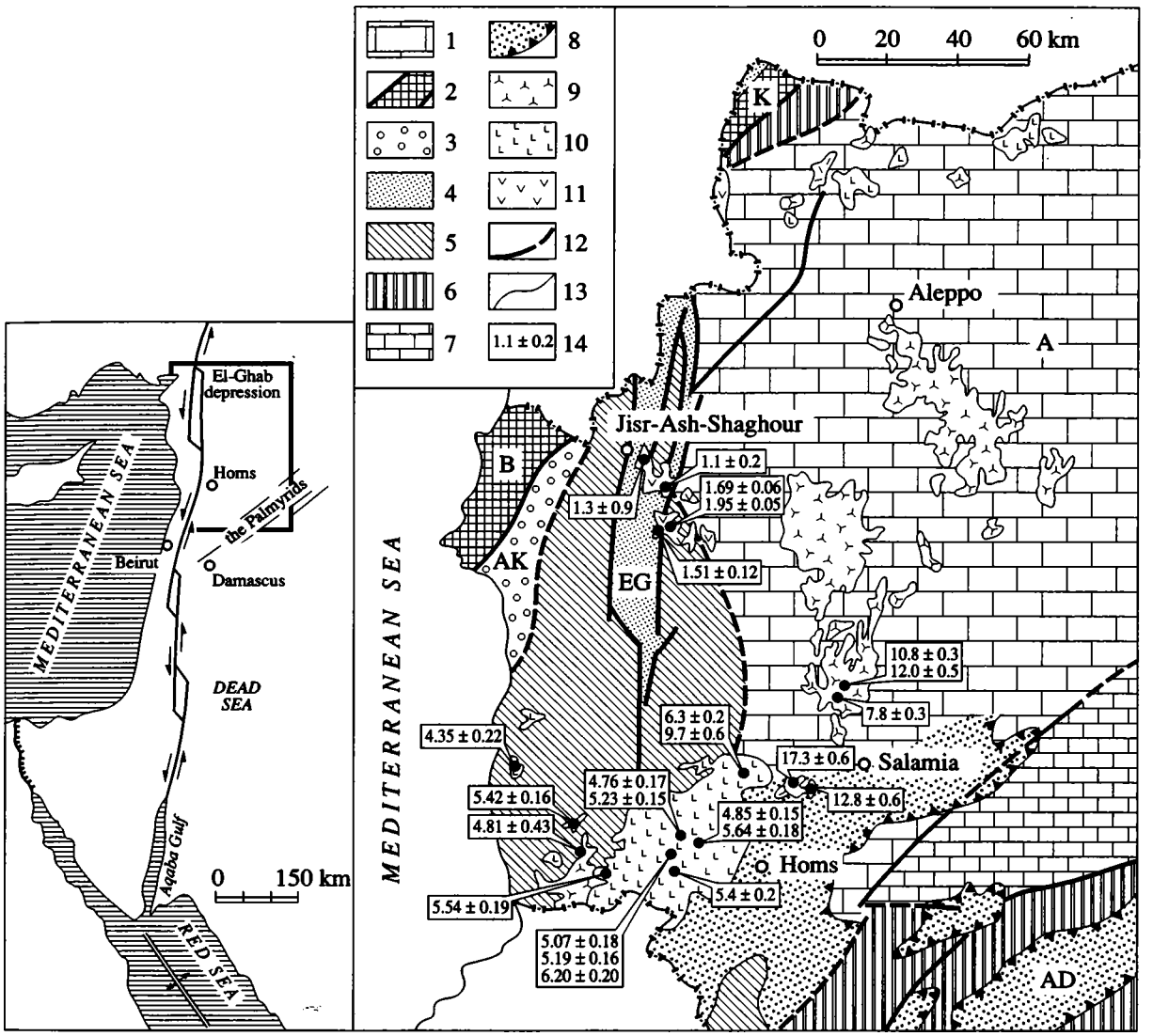


Fig. 1. Scheme of the tectonic position of the El-Ghab depression in the Levantine transform fault zone and the main geochronological complexes of the Late Cenozoic basalts of Western Syria, compiled on the basis of cartographic materials (*Geological Map...*, 1986) with tectonic elements after Leonov (in press). The Levantine transform fault in the inset map is shown according to B.K. Birchfield (1983). (1) the platform unaffected by the Alpine tectonogenesis and the Aleppo (A) uplift; (2) marginal parts of the platform with Alpine allochthonous complexes: (B) Bassit-Latakia block, (K) Kurdag block; (3–4) the rift belt: (3) Miocene grabens and Al-Kebir (AK) depression/graben; (4) the Pliocene–Quaternary grabens and El-Ghab (EG) graben; (5) arched uplifts and horsts; (6–8) intraplatform fold zone of Palmerids: (6) southern Palmyrids with deformed and partly removed cover, (7) northern Palmyrids, with a slightly deformed cover, (8) the inner and peripheral (piedmont) mollasic depressions: AD–Ad-Daw depression; (9) Miocene basalts; (10) Pliocene basalts; (11) Quaternary basalts; (12) faults; (13) other geological boundaries; (14) K–Ar age of basalts, in Ma.

The basalts of the nothern part of the El-Ghab graben (at the latitude of Jisr-Ash-Shaghour) compose a rather large massif with separate eruptive centers. Basaltic flows, which alternate with lacustrine Pliocene deposits, descend from this massif. On the eastern flank of the El-Ghab graben, the basalt sheets are now at about 500 m above the depression; they are ruptured by a series of meridional and northeastern faults and dissected by erosion. They are, in all likelihood, coeval with the Jisr-Ash-Shaghour basaltic massif.

In the northernmost part of El-Ghab, the Pliocene pelagic deposits were mapped overlying the Helvetian and Tortonian pelagic carbonate-bearing rocks (*Geological Map...*, 1963, 1986). The deposits are represented by horizontally bedded, dark gray, loose sandstones and clayey sands with occasional limestone interbeds containing thick-valved shells of littoral mollusks. A direct facial transition of the Pliocene pelagic deposits into the lacustrine–continental units of the El-Ghab depression was not established. But it was

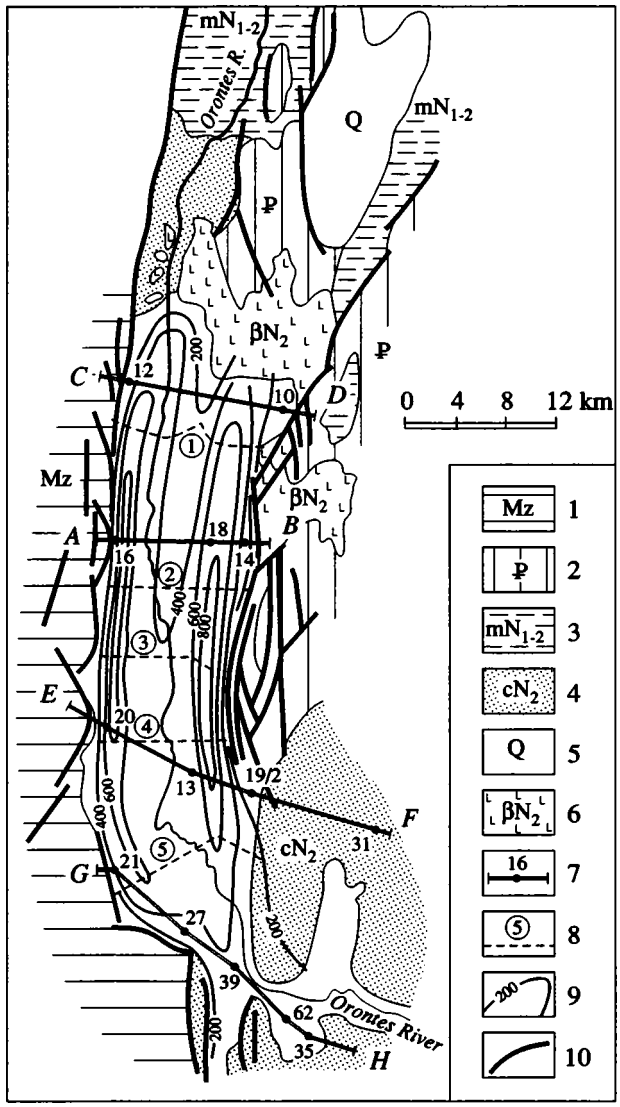


Fig. 2. The geological structure of the El-Ghab rift depression. (1) Mesozoic rocks of the horsted Coastal Mountains; (2) Paleogene–Miocene rocks of the Aleppo plateau; (3) pelagic Miocene–Pliocene deposits; (4) continental (mainly lacustrine) Pliocene deposits; (5) Quaternary deposits of various genesis; (6) Pliocene and Quaternary basalts; (7) the lines of bore-hole profiles (A–B) and well numbers (27); (8) geophysical profiles and their numbers (encircled); (9) isopachs, in m; (10) faults.

observed that all these beds overlie the Helvetian and Tortonian pelagic deposits, and that they are separated by outcrops of these rocks. The outcrops of these multifacies beds on the lefthand bank of the Orontes River (10 km north of Jisr-Ash-Shaghour) are only 1.5–2.0 km apart. Their stratigraphic situation and present-day geomorphological position positively imply that the upper parts of these multifacies beds are, in all likelihood, coeval.

The stratigraphy of the sediments filling the El-Ghab depression and their facial interrelations in different parts of the structure and beyond it are as yet insufficiently studied. Trifonov and co-authors (1991) have distinguished three complexes of deposits filling the El-Ghab depression, though their spatial and facial interrelations were not clearly defined. The first complex was determined in the fault zone of the southern continuation of the depression near the villages Ain-Hlakym and Ashek-Omar. It is represented by alternating units of conglomerates with pebbles of Cretaceous carbonate and siliceous rocks and, less often, of basalts and tuffs. There are also interbeds of sandstones, gritstones, clay–silt rocks, and marls. The thickness of these deposits reaches 100 m, and they are attributed to the alluvial–proluvial and, in the case of marls, to lacustrine facies. It is also known that upper beds of this complex contain faunal remains (mollusks), which are referred by Syrian paleontologists to the Pliocene. The second complex is observed in the north of the depression, near the town of Jisr-Ash-Shaghour. Its lower part is composed by marls and lignites with tuff interbeds, the upper part by basalts, and its thickness is estimated to be 15–20 m. Syrian paleontologists identified the Pleistocene age of fauna of freshwater mollusks. The third complex is represented by the Pleistocene and Holocene alluvium at the bottom and by slope facies on the flanks of the depression. The geological and paleomagnetic data allow us to outline the stratigraphic sequence of these complexes and to understand their position in the paleomagnetic scale. For example, K–Ar datings for the tuff–basalt complex of the Saraiya section are 5, 8, 7.5, and 10 Ma (Adjamian *et al.*, 1983). The paleomagnetic data have shown the variable polarity of magnetization of rocks in this section. Its age is estimated to be within a 5.8–8.9 Ma interval; it is also assumed, with lesser probability, that the age of its uppermost part may reach 4 Ma. From our point of view, the effusives of the Saraiya section should not be considered a complex of the El-Ghab rift depression proper. They belong to the Shin basalt plateau, which appeared as early as in the prerift stage. Later, along the meridional part of the Levant fault south of the El-Ghab graben, these thick basalt–tuff beds of the Shin plateau were broken up by a series of young tectonic dislocations, and narrow (fissurelike) graben structures were formed. Several K–Ar datings, obtained for the central part of the plateau (Sharkov *et al.*, 1994) (Fig. 1), fall in the interval ranging from 4.76 ± 0.17 to 6.2 ± 0.2 Ma. These datings refined the age of the effusives complex in the zone of the Levant fault. There are K–Ar datings ranging from 6.3 ± 0.2 to 9.7 ± 0.6 Ma for the eastern margin of the plateau, and supplementary K–Ar datings (5.42 ± 0.16; 4.81 ± 0.43; 5.54 ± 0.19 Ma) for the fragmentary parts of basalt beds exposed along the western slope of the Coastal Mountains, where basalts often overlie narrow watersheds. The geomorphological and hypsometric positions of the basalts permit us to connect the fragments of these beds with the complex of

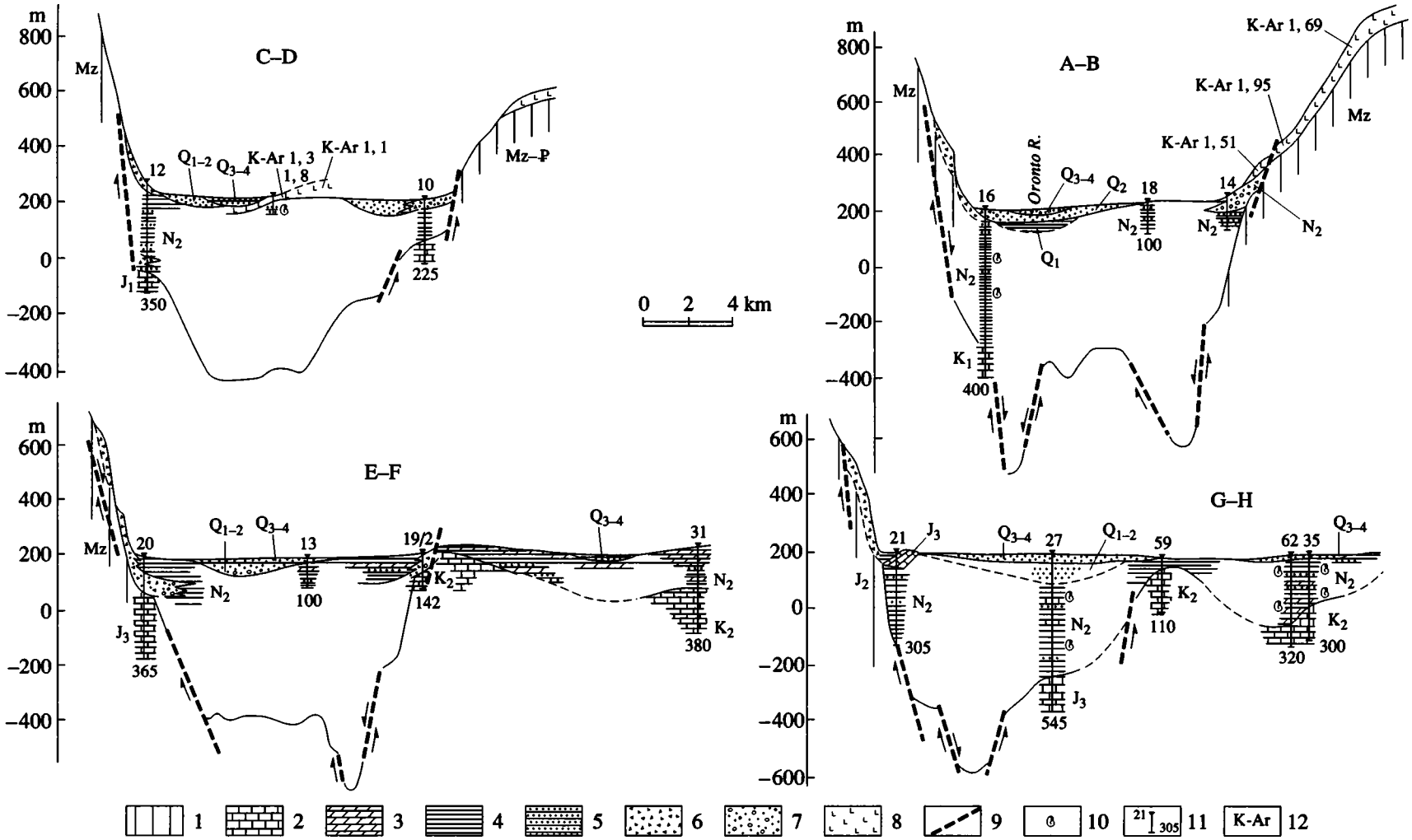


Fig. 3. Geological profiles (based on bore-hole and geophysical data) across the El-Ghab rift depression. (1) Mesozoic and Paleogene rocks; (2–10) Pliocene–Pleistocene deposits: (2) limestones; (3) marls; (4) clays; (5) sandstones and sands; (6) breccias and conglomerates; (7) basalts; (8) shingles with gravel and sands: (9) tectonic faults; (10) shells of mollusks; (11) wells, their numbers and depths, in m; (12) K–Ar datings.

the Shin plateau basalts, from which they propagate towards the Mediterranean Sea, locally covering up the Miocene and Pliocene pelagic deposits. Thus, the datings of the Shin plateau basalts reliably confirm that their geological age is within the late Miocene–early Pliocene interval.

The age of the second complex is in the 2.5–3.4 Ma interval and referred to the Gauss epoch; the age of the third complex lies between 0.7 and 2.5 Ma, and this complex was considered equivalent to the Matuyama epoch and, more probably, to its Pleistocene part, which is younger than 1.8 Ma.

Our work was focused on the El-Ghab rift depression proper and its flanks. We studied both the natural sections and the drilling data (unfortunately, without studying the cores). The structure of the depression includes sedimentation zones at the flanks and in the central part, where facial types of studied sections are strikingly different. The stratigraphy of these multifacies sections is as yet insufficiently studied, but their spatial relations and stratigraphic sequences are established, as we believe, with sufficient logical substantiation.

As noted above, the *western flank* of the depression is a steeply faulted multilock scarp with an enormous amount of olisthostrome formations of complicated genesis collected at the foot, including the gravity–avalanche accumulations of very large blocks of the slid-down and fragmented Jurassic and Cretaceous carbonate rocks that build up the Coastal Mountains. It is rather difficult to stratify these deposits or even to determine the initial time of their formation. Apparently, the process of their accumulation started with the activation of faults on the eastern flank of the El-Ghab depression at the beginning of riftogenesis of the terminal Miocene–initial Pliocene period.

Three complexes different in age are distinguished on the basis of karst activity in the olisthostrome deposits and their geomorphological position (Domas, 1994). The oldest (Miocene?) complex is characterized by mature karst forms in limestone blocks, by the presence of red beds filling karst cavities, and by the largest distance of blocks from the wall of the depression. These forms of karst probably developed during the initial avalanche sedimentation with carbonate blocks. Two younger (Pliocene and Pleistocene) complexes[1] display a lesser degree of karst erosion and geomorphological confinement to the rupture cirque on the faulted slope of the Coastal Mountains. These two complexes are in a higher hypsometric position over the bottom of the El-Ghab depression.

The interrelations of the slope deposits with the lacustrine formations are established from the data recovered by wells drilled in the flank part of the depression (Fig. 3, Wells 20, 21, 12). In this area, the gravity–proluvial deposits are composed of coarse breccias of the Jurassic and Cretaceous carbonate rocks derived from the fault slope of the Coastal Mountains, which show facial gradations to marls, clays, and sands of the upper part of the lacustrine sequence. The thickness of the bank deposits reaches tens of meters, but, according to drilling data, these facies are confined only to the near-wall part of the graben and cannot be traced in its center. This fact implies a great steepness and depth of the western flank of the graben, as is clearly shown by drilling and geophysical profiles (Fig. 3).

The separate blocks of carbonate rocks, which were derived from the rising flank of the rift depression and then slipped down, are enormous. For example, during the geological survey (*Geological Map...*, 1963) near the western wall of the El-Ghab graben, an Upper Jurassic limestone block covering 1.5×2.0 km^2 was mapped. The outcrops are separated from the wall by a narrow (0.3 km) trench covered with Quaternary proluvium. The limestone block is intensively dissected and slightly elevated over the El-Ghab plain and surrounded by lacustrine deposits. The Upper Jurassic bedrock outcrops are located 3 km to the west on the steep slope of the Coastal Mountains scarp. The bedrocks form a monocline gently sloping to the west (5°–10°); its lower part is composed of Middle Jurassic rocks, separating the upper beds from the limestone massif. The base of the Upper Jurassic in the scarp of the ridge is fixed at a hypsometric level of about 700 m, whereas the outcrops of these rocks on the surface of the depression lie at an altitude of about 300 m. Therefore, a brief analysis of the results of the geophysical survey testifies that the Upper Jurassic limestones and dolomites in the depression are in allochthonous position and represent an enormous rock mass derived from its initial position and slid down the slope along the fault. The drilling data confirm this statement (Fig. 3, profile G–H). At the edge of the block, the core from Well 21 reveals an upper bed (0–10 m) of brown lacustrine clays, then a unit of greatly fissured dolomites (10–45 m), and a layer of lacustrine sediments below them, which is composed of dense brown clays with infrequent shingle and sandstone interbeds (45–305 m).

In the general El-Ghab stratigraphic section, the position of the conglomerates outcropping at the eastern side of the Masiaf graben near the road to the town of Jableh (the village of Abou Qubes) is specific. The conglomerates form a monocline up to 500 m thick and contact the Jurassic limestones on the graben's flank along the tectonic boundary with a distinctly deliniated shearing transformation zone (up to 25 m thick). The conglomerates are steeply inclined to the east towards the depression (up to 70°), but further on, their dip is gentler (up to 20°). At the base of the conglomerates, there is a bed (up to 50 m thick) of coarse breccias of Jurassic rocks containing blocks (up to 3–5 m and larger) of limestones embedded in the crushed carbonate matrix. At the top of the bed, the interbeds (0.5–1.5 m) and lenses of red sandstones contain gravel and shingle.

[1] Among the younger avalanche formations, Domas (1994) distinguishes the Miocene–Pliocene and Pliocene complexes.

Above, there is a sand–shingle band (up to 100 m) with a well-seen oblique lamination and poorly rounded rock debris. Still higher in the section (starting at 160 m), interbeds of pink and light gray marls (0.2–0.3 m) and red clays begin to occur. In the 200–250-m interval there is an increase of roughly rounded material in the composition of the conglomerates, and above it, interbeds of red clays appear again. At about 300 m from the base of the section, there is a bed of coarse breccias with large (up to 1–1.5 m) limestone blocks. Still higher in the section, the small-pebble conglomerates enclose a greater number of interbeds of sandstones and red clays. In the uppermost part of the conglomerate bed, the sand, clay, and marl interbeds indicate the facial substitution of coarse clastic rocks of the proluvial and partly olisthostrome type by the lacustrine deposits of the central part of the depression.

The section described above was studied with respect to its palynology (Fig. 4). The samples were collected from clayey intercalations among conglomerates and breccias. The overall content of the spore and pollen in spectra is uniform, and they show that pollen of the arborescent–shrub group is dominant (40–70%). The share of herbaceous pollen varies from 30 to 48%. The conifers are represented mainly by *Pinus* pollen; occasionally among them there are also *Podocarpus, Picea,* and Taxodiaceae. *Alnus* dominates among the angiosperms, and there is a large amount of pollen of *Carpinus,* Ericaceae, Oleaceae, *Quercus, Ulmus*, and *Juglans.* Most of the herbs and bushes belong to Gramineae, Compositae, Cyperaceae, and herbatum mixtum. There are also spores of Polypodiaceae, *Sphagnum, Felicales, Pteris, Lycopodium,* and *Selaginella.* This composition of the spore–pollen spectra corresponds to extensive mountain areas covered with spruce–pine woods, foothills with coniferous–broad-leaved forests, and plains with maquis and meadow vegetal groups. A considerable amount of pollen of arborescent vegetation and certain pollen taxa of *Picea, Liquidambar, Fagus, Tilia, Nyssa, Urtica,* and spores of *Sphagnum,* and *Selaginella* are indicative of a rather cool and more humid subtropical climate than nowadays, whereas the large amount of pollen of Cyperaceae, Hydrocharitaceae, *Myryophyllum, Menyanthes,* and *Typha* indicates the proximity of aquatic or, probably, palustrine areas.

The generally uniform composition of the spore–pollen spectra and the presence of an extensive amount of taxa exotic for the vegetation of present-day Syria, such as *Fagus, Tilia, Nyssa, Camptonia, Carya, Platycarya,* and *Myrica* implies that the conglomerate sequence is rather ancient. The spectra obtained are similar to those of the Pliocene marine section near the village of Jinndiriye (Devyatkin *et al.,* 1996) and to the Pliocene spectra of the Nahr-Al-Kebir River basin (Husein and Rybakova, 1973). These plant communities differ from the upper Pliocene spore–polen spectra obtained in northwestern Syria (Simakova, 1994; Golovina *et al.,* 1996). The palynological data allow us to suppose that the formation of red conglomerates on the western flank of the El-Ghab depression took place in the first half of the Pliocene. The relatively warm and more humid climate of the early Pliocene is indicated by palynological data for other Mediterranean territories as well (Horowitz, 1980; Selli *et al.,* 1977; Suc, 1981).

The central part of the El-Ghab depression, by geological data, is a graben filled with lacustrine sediments up to 1 km thick, and their base is 700 m below sea level. The deepest wells (Fig. 3, profiles C–D, G–H) penetrated through the lacustrine sequence to a depth of 450 m. In Well 27, a 115-m thick unit of coarse sands and clays with gravel (the Quaternary deposits of the Orontes River valley) overlies a 320-m member of uniform gray unconsolidated calcareous clays with sand, shingle, and gravel intercalations. Below this bed, an interlayer of basalts (10 m) and well-cemented carbonate breccia up to 100 m thick is deposited at the bottom of the section on the Mesozoic basement. In Well 18 (profile A–B), the lacustrine deposits are likewise composed of gray carbonate clays with sand and peat interbeds (7 m). Occasionally, the cores of the wells show beds of marls and limestones, often with freshwater molluscan fauna and coalified leaf flora remains.

Lacustrine deposits are typical not only of the El-Ghab rift depression, but are also observed in outcrops along the entire southern end of the eastern side of the graben; they are also reached by wells on the plain in the latitudinal part of the Orontes River Valley in the Asharne basin 20 km east of the brink of the graben proper. Therefore, it is reasonably well established that the zone of the lacustrine sedimentations was not confined to the rift itself, but also extended southeast of the rift.

The upper part of the lacustrine section of the El-Ghab depression is observed in the quarries and the walls of canals. For example, the following section was studied in the north of the depression at a bridge near the village of Karkour in the channel walls of the present-day Orontes River (from bottom upwards):

(1) clays, black, consolidated, homogeneous, vaguely laminated, visible thickness is 0.5 m;

(2) clays, black and sandy, grading upwards to dark gray clay and containing a considerable quantity of unionides and gastropods, thickness is 0.5 m;

(3) clays, and silts, light gray, to greenish, horizontally laminated, with occasional shells of freshwater mollusks, thickness is 3.0 m;

(4) clays, gray, sandy, filled with shells of freshwater mollusks; most shells of unionids have jointed valves, thickness is 1.0 m;

(5) clays, gray, sandy, horizontally laminated; at the top (0.5 m) they are they variegated calcareous and columnar in structure, thickness is 4.0 m;

(6) cavernous limestone with shell inclusions, thickness is 0.7 m;

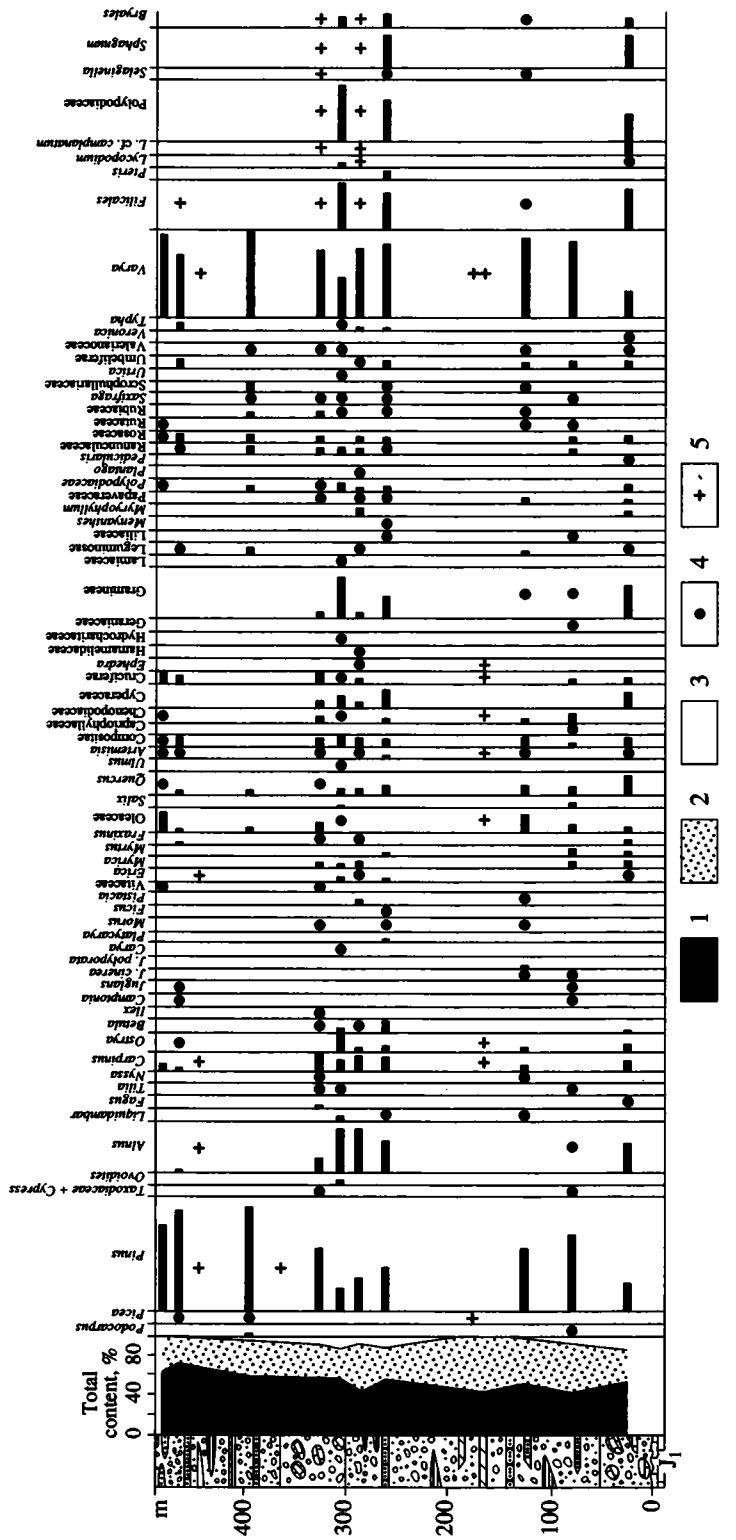


Fig. 4. The spore–pollen diagram for the Pliocene conglomerates in the western flank of the El-Ghab depression. (1) pollen of trees and shrubs; (2) pollen of herbs and shrubs; (3) spores; (4) single pollen and spore grains; (5) accessory pollen and spores of scanty groups without percentage count (symbols as in Fig. 3).

(7) sandstones with fine shingles grading upwards into sands, which are covered by recent soil. Rounded ferruginated shingles belong to the alluvial type, the thickness is 1.0 m.

Two assemblages of freshwater mollusk fauna were studied in the Karkour section. The older (lower) one was recovered from layers (2) and (4) and includes the following species: *Theodoxus jordani* (Sowerby), *Melanopsis orientalis* Buk., *M. biliotti* Buk., *M. binodosa* (Blanck.), *Cincinna* (*Athropidina*) *saylcyi* (Bgt.), *Bithynia*(?) *phialensis* (Condrad), *Anisus leucostomus* (Mill.), *Giraulus piscinarum* (Bgt.), *Planorbis planorbis antiochianus* Locard, *Planorbarius* sp.,*Hippeutis euphaea* (Bgt.), *Lymnaea* (*Peregriana*) sp., *Leguminaia* sp., *Rytia* sp. nov. 1, *R.* sp. nov. 2, *R.* sp. nov. 3, *Eolymnium* sp. nov. 1, *E.* sp. nov. 2, *Corbicula* sp., *Euglesa* (*Henslowiana*) *suecica* (Clessin), and *E.* (*Casertiana*) *casertiana* (Poli.). The age of the assemblage is dated by the presence of *M. orientalis* and *M. biliottii*, which are known from the lower Pliocene Apolakkia and Monolitos formations of Rhodos Island in the Aegean Sea. The fauna of the Apolakkia Formation contains late Ruscianian mammals, e.g., *Mimomys occitanus* (Willmann, 1981). The lacustrine clays exposed 500–700 m to the north of this section and containing the malacofauna of the lower assemblage, are overlain by a thin basalt flow, the K–Ar age of which is 1.8 ± 0.1 Ma.

A younger (upper) molluscan assemblage was established in the uppermost part of the Karkour section (layer 6) in compact limestones. Shells of mollusks collected on the western flank of the depression, 1 km south of the Nibl Khatib village likewise belong to this assemblage. In the last locality, the shells were found in the clayey sand on the surface of the depression. The assemblage is represented by *Siriomargaria apameae* (Blanck.), *S.* sp nov., *Melanopsis* cf. *polyptycha* Neum., *M.* sp., *Cincinna* (*Athropidina*) *saylcyi* (Bgt.), *Bithynia* (?) *phialensis* (Conrad), *Semisalsa longiscata* (Bgt.), *Falsipyrgula rabensis* (Blanck.), *Gyraulus piscinarum* (Bgt.), *Leguminaia* sp., *Pseudunio* sp. nov., *Potomida delesserti* (Bgt.), *P.* sp. nov.1, *P.* sp. nov. 2, *P.* sp. nov. 3, *Eolymnium kincelbachi* (Schutt), *E.* cf. *terminalis* (Bgt.), *E.* sp., *Nemrodiana* aff. *tigridis* (Bgt.), and *Dreissena bourgignati* Lokard. Characteristic forms of the assemblage are *Siriomargaria apameae*, *S.* sp. nov., *Melanopsis* cf. *polyptycha*, *Falsipyrgula rabensis*, *Pseudunio* sp. nov., *Potomida* sp. nov. 1, *Eolymnium kincelbachi*, and *E.* cf. *terminalis*. These mollusks are found neither in the earlier deposits, nor in present-day fauna (Schutt, 1983). There is a considerable renewal of the malacofauna, probably signifying a hiatus between the upper and lower assemblages. The malacofauna of the upper assemblage apparently originates from the so-called freshwater El-Ghab conglomerates, and its age is traditionally determined as the late Pliocene (Schutt, 1988). The correlation of these deposits by freshwater fauna is as yet unclear, and the following facts should be taken into account: (1) *Melanopsis polyptycha* is typical of the upper Pliocene deposits of the Kos Island (the Aegean Sea), which contain the Villafranchian fauna of mammals (Willmann, 1981); (2) large forms of *Pseudunio*, similar to *P.* sp. nov., are known from the middle Pleistocene deposits (according to the West European Scale) of Moldavia (Chepalyga, 1967); (3) the aspect of the fauna, on the whole, resembles that of the Pliocene Poratian molluscan fauna of Moldavia, but this and Syrian faunas lack common species; (4) *Potomida* sp. nov. 1 is similar to *P. rosseti* (Cabalescu) from the lower Romanian (the upper Pliocene) of Rumania (Papaianopol, 1989). This evidence restricts the age of the upper assemblage fauna to the late Pliocene.

Near the town of Jisr-Ash-Shaghour, on the left-hand side of the Orontes River valley, there is a section in which basalts (more than 20 m thick) overlie the lacustrine sediments represented by white horizontally laminated marly clays, at the top of which there is a layer (0.5 m) of dark gray clays with abundant shells of freshwater gastropods *Melanopsis polyptycha* Neum., *M.* cf. *blanckenhorni* Schutt, *Cincinna* (*Athropidina*) *saylcyi* (Bgt.), *Bithynia* cf. *badiella* (Kuster), and *Gyraulus piscenarum* (Bgt.). The absolute K–Ar age of basalts overlying the lacustrine deposits in the section is 1.3 ± 0.9 Ma, whereas at the eastern end of the basalt mass the age value is 1.1 ± 0.2 Ma. Thus, the age of the top of the lacustrine sequence in the El-Ghab depression can be assumed to be not older than the early Pliocene. The lower part of the El-Ghab lacustrine sequence is probably the early Pliocene in age, though definite evidence is still lacking.

The above-described section of lacustrine deposits overlain by basalts was studied in palynological aspect. It was established that the spore–pollen spectra are generally characterized by the predominance of arborescent pollen (45–75%). The dominant pollen taxa are *Pinus*, and *Picea*, among conifers and Oleaceae; *Quercus*, and *Carpinus*, *Juglans* among the gymnosperms. The herbs are represented mainly by the pollen of the families Compositae, Chenopodiaceae, Gramineae, Rosaceae, and Umbeliferae. The content of spores is low; among them are those of *Lycopodium*, *Anemia*, Polypodiaceae, and *Bryales*. These spore–pollen spectra permit us to reconstruct the vegetation of the evergreen sclerophyllous forests of the piedmonts. The mountain areas were covered with pine–oak forests with spruces and firs. On the plains, the meadow–steppe vegetal group dominated. The climate was somewhat more humid and warmer than today, with seasonal humidification typical of the Mediterranean subtropics. The palynological spectra are well correlative with those of the upper part of the Mardido marine section in the Al Kebir depression and can be dated to the early Pleistocene (Simakova, 1994; Golovina *et al.*, 1996; Devyatkin *et al.*, 1996).

The eastern side of the El-Ghab depression is characterized by a number of sections of the Pliocene–Qua-

ternary deposits observed along its fault boundary from the latitudinal area of the Orontes River in the south to the Qalet Al-Madiq Village in the north. The deposits are composed of lacustrine facies: light-colored clays, marls, sands, and fine rounded shingles, up to 20–30-m thick in total and horizontally banded. In the north, along the steeply raised side of the depression (the western flank of the Jebel az-Zawiya block uplift), the lacustrine facies grade into a bed of brown and reddish shingles and conglomerates with clay and sand intercalations (up to 30 m). The rocks show a considerable carbonate cementation of the clastic material. At the base of the coarse layer, there are interbeds of greenish gray clays and marls of the lacustrine type. This fact suggests that the sedimentation phase of the lower part of the shingle and conglomerate beds corresponds to that of the lacustrine sequence in the center of the depression.

In the upper part of the section (a quarry near the Qalet Al- Madiq village), a weathered horizon can be traced at the top of the conglomerate bed. It is composed (from the base upward) of a layer of carbonatizated underlying rocks (conglomerates and sands) and bright red lateritelike clays deposited in pockets (up to 1 m). The weathered horizon discordantly overlies the conglomerates. Above the weathered horizon, there are brown, obliquely laminated, rounded shingles of the proluvial type. The weathered horizon divides the two sequences of fluvial deposits, thus implying a hiatus in sedimentation. We should note here that on the western side of the El-Ghab depression, the upper Pleistocene complex of olisthostrome formations was subjected to weathering.

Still further north, a quarry near the Halubi village clearly reveals basalts descending from the watershed on the eastern flank of the El-Ghab depression and covering a bed of sedimentary rocks. The latter are represented (at the top) by proluvial brown and red conglomerates with sand and clay lenses of the same color; their total thickness reaches 20 m. Below, they are substituted by light gray clays, greenish marls with interbeds of sand, gravels, and rounded small shingle of the lacustrine formations (12–15 m thick). The basalts are of the late Pliocene age (*Geological Map...*, 1963). The K–Ar datings of basaltic flows were carried out at three sites: at the top of the eastern flank near the Halubi village, in a quarry on the slope where basalts overlie the lacustrine–proluvial complex of sediments, and at the base of the eastern side. The results are, respectively, 1.69 ± 0.06, 1.95 ± 0.05, and 1.51 ± 0.12 Ma; they refine the age of the basalts and confirm their coeval appearance with the basalts of the Jisr-Ash-Shaghour mass (Fig. 1). Moreover, we can deduce that the underlying sub-basalt complex of proluvial and lacustrine deposits on the eastern side of the El-Ghab is pre-early Pleistocene in age.

THE LATE CENOZOIC BASALT MAGMATISM OF THE EL-GHAB GRABEN

The study of magmatic processes has yielded important data on the endogenic evolution of the El-Ghab graben area. The process of basalt magmatism began about 21 Ma ago in the northern part of the Syrian–Jordanian plateau, and since that time continued with short interruptions until historical times. At least five stages of this magmatism were identified.

(1) The early Miocene (21–17 Ma ago). The basalt magmatism ocurred mainly in the northern part of the Hauran–Druz plateau and partly at the base of the Shin plateau.

(2) The middle Miocene (14–11 Ma ago). During this period, magmatism was mainly active within the meridionally stretching Aleppo plateau east of the El-Ghab graben, as well as partly on the Shin plateau and the western part of the Hauran–Druz plateau; together, these areas of basalt magmatism compose a wide intermittent band east of the young Levant rift zone and parallel to it.

(3) The late Miocene–early Pliocene (10 to 4.5 Ma ago). The basalt magmatism of this period formed two large Shin and Korazim basalt plateaus along the axis of the Levant transform fault on both sides of the Palmyrid fold system. The larger part of the isometric Shin plateau is situated in Syria, and the basalts on both sides of the fault are of the same age and composition. The Korazim plateau is covered with Neogene deposits and situated on the territory of Israel within the area of the tectonic block on the northern bank of Kinneret Lake (Sea of Galilee) and in the axial part of the Levant rift zone. The basalts in this area are generally younger (5.1–3.6 Ma; Heimann and Ron, 1993).

(4)The late Pliocene–Pleistocene (3.6–0.3 Ma ago). The basalts of this age are deposited on the Hauran–Druz plateau (including the Korazim block) and on the plateau in the region of Jisr-Ash-Shaghour. In this locality, in the El-Ghab graben and its environs, the basalts are coeval. Small basalt areas were also formed at the same time near the town of Banias in the north of Syria and in the Euphrates River valley.

(5) The Holocene basalts are deposited on the Hauran–Druz plateau and, apparently, in northeastern Syria, mainly in the region of the Euphrates valley.

The basalts studied on the territory of Eastern Syria are typical continental plateau-basalts of the intraplate type. They are represented mainly by the Fe–Ti-alkaline basalts, including olivine basalts, and, to a lesser extent, by hawaiites, mugearites, and occasional trachytes (Ponikarov *et al.*, 1967; Sharkov *et al.*, 1987). These basalts are typical of mantle plumes that generate the Phanerozoic intraplate magmatism (Wilson, 1989). Only the middle Miocene basalts of the Aleppo plateau belong to the type of continental tholeiites and are likewise enriched by iron and titanium. According to modern views, they usually appear as a result of advanced melting of the plume matter or due to

contamination of basaltic magmas by the continental crustal material (Wilson, 1989).

It should be noted that magmatic activity manifestations on this territory were grouped in the vicinity of the Levant transform fault. Untill the late Miocene, magmatic events centered east of the future rift. The concentration of magmatic activity of mantle genesis in this locality is evidence of a linear submeridional asthenospheric diapir probably responsible for the formation of the late Miocene–Pliocene–Quaternary transform fault, which is still under development. And only later, at the pre-rift stage, the formation of the Shin and Korazim plateaus began under complete control of the Levant fault structure. It is remarkable that, on the Shin plateau, the feeding channels of lava beds, represented by dykes, have different orientations on the eastern and western flanks of the fault: in the east, they have, as a rule, a northwestern strike (the azimuth is about 330°), while in the west sublatitudinal and northeastern directions prevail. Therefore the orientation of the dykes coincides with the kinematic stress field that appears during the sinistral displacement and obviously implies the synkinematic character of magmatic and tectonic processes. The absence of magmatism within the Palmyrid area at that time apparently testifies to the reorganization of the deep structure of the region in response to subduction of the Palmyrid roots and asthenospheric mantle flow into weakened zones.

ROCK ASSOCIATIONS AND STRATIGRAPHIC COMPLEXES IN THE HISTORY OF THE EL-GHAB RIFT ZONE DEVELOPMENT

The history of the geological development of the El-Ghab rift is clearly connected with the geodynamics of the asthenosphere. At the initial stages of its development, this depression was formed as a compensating trough on the western periphery of the asthenospheric diapir that appeared in the early–middle Miocene. Apparently, the top of this diapir was, at that time, at a considerable depth, and its influence could not cause the formation of a rift structure, though it caused the origin of a sedimentary basin over it. This is probably compatible with the tholeiitic character of magmatism in the middle Miocene on the Aleppo plateau. In the late Miocene–early Pliocene, the centers of mantle activity shifted towards the Levantine fault and caused the appearance of the Shin and Korazim pre-rift plateaus. The El-Ghab area continued its development as a compensatory sedimentary basin. However, when the apical part of the asthenospheric diapir was contracted by the subsiding roots of the Palmyrids, a new and not-so-deep-seated mantle plume appeared in this place. Eventually, a large rift depression was formed by both the mantle diapirism activity and the displacement processes along the Levant fault.

An analysis of the stratigraphic and spatial positions and of the facies interrelations of sedimentary and magmatic beds in the El-Ghab depression and along its flanks allows us to identify the following rock associations and stratigraphic complexes as corresponding to the stages of development of this structure.

(1) The prerift (platform) complex includes the upper part of the Arabian platform cover. It is composed of the Paleogene and Miocene marine deposits now still observed on the Aleppo plateau and the western slope of the Coastal Mountains. At an earlier period, these rocks probably covered the entire area of the rift zone, which apparently was not structurally and morphologically expressed at that time. Individual basalt horizons with the K–Ar age of 12.8 to 7.8 Ma are mainly observed east of the rift zone. In one of the sections, near the Tahunet El-Vahshie village, a basalt flow (K–Ar dated at 12.8 ± 0.6 Ma) is found covering the Middle Eocene marine deposits and overlain by the eroded Pliocene lacustrine sediments. The complex of "prerift" basalts was established on the Hauran–Druz plateau (Sharkov *et al.*, 1994), and Miocene basalts are known on the Golan Heights (Steinitz *et al.*, 1978; Shalin and Steinitz, 1987). The late Miocene basalts (8.8 Ma) in the northern part of the Dead Sea rift were recovered by drilling in the Hula depresseion (the Notera Well in Israel) from a depth of about 2400 m (Heimann and Steinitz, 1989).

(2) Rock-complexes of the prerift and initial rifting stages are represented by volcanites of the Shin plateau, 350 m thick at the center and 50 m thick on the periphery (Novikov *et al.*, 1993). The basalts of the plateau are divided by horizons of red weathering crusts. The Shin basalt area is located south of the southern end of the El-Ghab depression, actually in the zone of the Levantine fault. This area was apparently formed at the very beginning of rifting by the appearance of deep meridional faults, along which volumes of extrusives penetrated and formed the basalt plateau of about 1200 km^2. Extrusions repeatedly occurred (up to 30 flows), alternating with periods of lower magmatic activity, during which an intensive formation of red weathering crusts of considerable thickness took place. There are no sedimentary rocks in the sections of the volcanic rocks of the Shin plateau. The K–Ar ages of basalts (nine determinations) range here from 6.3 ± 0.2 to 4.79 ± 0.17 Ma (Fig. 1). Older values (9.7–17.3 Ma) probably correspond to the prerift basalts. The terrigenous–sedimentary rocks in this stratigraphic interval (the end of the Miocene–beginning of the Pliocene) are as yet unknown in the El-Ghab rift zone.

In the southern branch of the Levantine fault, in the Hula depression (the Notera Well), a complex of basalts alternating with lacustrine deposits, such as clays, marls, and lignites up to 800 m thick, was established in a depth interval ranging from 1600 to 2400 m (Heimann and Steinitz, 1989). The K–Ar ages of basalts are from 3.34 to 4.08 Ma as in the complex of plateau-basalts on the Golan Heights and in Galilee. It is important to note that there are no sediments in the interval between the prerift Miocene basalts (8.8 Ma)

and the Pliocene basalts (4.1 Ma). This is an indication that, in the southern part of the Levantine rift zone, the opening of the rift and the formation of deep grabens filled with lacustrine deposits began with the onset of the Pliocene time.

(3) The synrift sedimentary complex of the El-Ghab depression is studied in three sedimentary zones: the western, the eastern (both near flanks), and the central. It was established that the oldest early Pliocene deposits of the depression are probably the conglomerates observed along its western wall in the Masiaf graben; their formation started when the high slope of the Coastal Mountains already existed. The lithological–genetic peculiarities permit us to consider the conglomerates as proluvial-type deposits with olisthostrome horizons at the base of the section. In its upper part, a transition into lacustrine facies is recorded. The palynological evidence implies the early Pliocene age of these deposits and concurrent vertical landscape zonality: the Coastal Mountains with forests and the piedmont steppe zone with maquis. The area of the depression itself was covered with flooded and swamped plains.

In the central part of the El-Ghab depression, the sedimentation evidently began also in the early Pliocene, though the lowest part of the section is still not reached because the wells were drilled only through the upper half (450 m) of the lacustrine sequence. During the entire Pliocene, the lacustrine deposits accumulated not only in the El-Ghab rift but further southeast beyond its present-day tectonic margin. The Pliocene marine transgression in the eastern Mediterranean was manifested on the Syrian and Turkish coast areas as ingression bays along grabenlike troughs. In the northern part of the El-Ghab, the Pliocene marine and freshwater facies are only 2 km apart and divided by a shallow uplift of pre-Pliocene rocks (*Geological Map...*, 1963). There are reasons to suggest that the El-Ghab lacustrine basin of the Pliocene time could have been connected with an ingression bay during the highest sea-level phase. This connection took place along a tectonically weak zone now inherited by the Orontes River valley north of Jisr-Ash-Shaghour. The Pliocene marine facies in the rift itself are not as yet discovered, and the molluscan fauna in lacustrine deposits is of the freshwater type. This circumstance hinders the reconstruction of a direct connection between the sea bay and the El-Ghab freshwater basin. Apparently, the sea ingression maximum and the El-Ghab "lacustrine transgression" occurred very close in time within the late Pliocene–early Pleistocene interval and are conventionally correlated with the Calabrian transgression n the Mediterranean region (Devyatkin *et al.*, 1996). The Calabrian abrasion–accumulation surface is well defined along the Coastal Mountains in their maritime (western) part at the absolute heights of 200–250 m, approximately corresponding to the upper level of the El-Ghab lacustrine sediments of that age.

The time of the El-Ghab lacustrine transgression evidently correlates with the interval of relative stability of tectonic movements along the sides of the graben. Climatic conditions (warm, with seasonal humid periods) were favourable for intensive weathering of the upper Pliocene rocks on the flanks of the depression. The weathered horizon that was formed at that time can probably serve as a lithological–stratigraphic datum level for a subdivision of the synrift deposits.

In the early Pleistocene, two large basalt massifs appeared in the northern part of the El-Ghab and on the eastern flank of the rift. The Jisr-Ash-Shaghour massif is located in the southern part of the Jebel Oustani horst–anticline; it is slightly faulted and dissected by erosion. The basalt massif on the eastern flank of the rift stretches along the Jebel az-Zawiyah uplift; it is disrupted by faults, and its lifted sides are eroded. The supposed sinistral displacement along the eastern bank of the El-Ghab (Kopp *et al.*, 1994) was probably the cause of lateral displacements within the massif itself, though we failed to detect these movements.

The tectonic development of the El-Ghab depression in the Pleistocene has inherited the main features of the Pliocene rifting stage. Walls of the depression continued to rise along a system of lateral faults and caused the formation of a younger generation of rudacous rocks accumulate near the base of the uplifted blocks. In the Pleistocene, the Orontes River valley was shifted laterally from the eastern to the western flank (Van Liere, 1960–1961); this displacement possibly was associated with an uplift along the Jebel az-Zawiyah block. The central part of the El-Ghab depression was filled with lacustrine and alluvial deposits; the tectonic uplift in the Jisr-Ash-Shaghour area and the basalt massif that appeared there blocked this depression from the north. In the Jisr-Ash-Shaghour region and further south the position of the top of the Pliocene deposits seems to be relatively uplifted. At present, the erosion incision in the Orontes River valley has reached the northern end of the depression and advanced in it only for 5 km, to a point located south of Jisr-Ash-Shaghour.

CONCLUSION

In the El-Ghab rift depression, we have identified several lithologic–stratigraphic complexes corresponding to the following stages of tectonic development of the structure:

(1) the prerift (platform) stage of the Miocene marine deposits with a few basalt horizons;

(2) the anterift stage and the very beginning of rifting, which formed a complex of effusives and weathering crust horizons on the Shin plateau at the end of the Miocene–beginning of the Pliocene;

(3) the rift stage that was responsible for olisthostrome formations on the flanks of the depression and accumulation of volcanic and lacustrine deposits in its central part during the Pliocene–early Pleistocene. In

the rift zone, this stage is implied by a lacustrine transgression, the maximum of which probably coincided with the Calabrian marine transgression.

In the El-Ghab rift zone, mainly to the south of it, the basalt magmatism was particularly active in the anterift and rift stages (late Miocene–Pliocene). During the second half of the rift stage (late Pliocene–early Pleistocene), the magmatic activity migrated to the north of the depression, perhaps owing to the deep structural reorganization of the region. The palynological data allow us to reconstruct the sufficiently humid climate and altitudinal landscape zonality of the early Pliocene, and to show that the late Pliocene and early Pleistocene were periods of discernable alternation of peaks of relative aridity and humidity against the background of moderate temperature variations. The two identified freshwater molluscan assemblages were used for correlation of the Pliocene and early Pleistocene lacustrine deposits of the El-Ghab rift with coeval strata in other regions.

ACKNOWLEDGMENTS

This study was carried out according to the program of the Russian–Syrian Expedition. The field research was undertaken with the support of the General Administration of Geology and Mineral Resources, Ministry of Petroleum and Mineral Resources of Syria.

We also acknowledge the support of the Russian Foundation for Basic Research, project no. 93-05-9839.

REFERENCES

Adjamian, J. and Jamal, N.E., *Geological Map of Syria, Scale 1 : 50 000, Explanatory Notes of Qallat Al Housen, Sheet NI 37-M-3-d,* Damascus: Ministry of Petroleum and Mineral Resources, 1983.

Birchfield, B.K., The Continental Crust, *V mire nauki,* 1983, no. 11, pp. 60–72.

Besancon, J. and Sanlaville, P., Remarques sur la geomorphologie du Ghab (Syrie), Chapitre II, Paleolithique de la vallee moyenne de l'Orontes (Syrie), *BAR International Series,* 1993, no. 587, pp. 41–56.

Chepalyga, A.L., *Antropogenovye presnovodnye mollyuski yuga Russkoi ravniny i ikh stratigraficheskoe znachenie* (Anthropogene Freshwater Mollusks in the South of the Russian Plain and Their Stratigraphic Implications), Moscow: Nauka, 1967.

Devyatkin, E.V., Dodonov, A.E., Golovina, L.A., *et al.,* Upper Pliocene–Lower Pleistocene Marine Deposits of Western Syria: Stratigraphy and Paleogeography, *Stratigr. Geol. Korrelyatsiya,* 1996, vol. 4, no. 1, pp.71–81.

Domas, J., The Late Cenozoic of the Al Ghab Rift, NW Syria, in: *Sbornik geologickych ved,* Praha: Antropozoikum, 1994, no.21, pp. 57–73.

Golovina, L.A., Gablina, S.S., and Simakova, A.N., Paleogeographic Interpretation of the Paleoflora from the Pliocene–Pleistocene Sediments of Western Syria, *Stratigr. Geol. Korrelyatsiya,* 1996, vol. 4, no. 2, pp. 102–105.

Geological Map of Syria, (I-36-XXIV, I-37-XIX), V.D. Technoexport, 1963.

Geological Map of Syria, 1:1 000 000, Damascus: V.D. Technoexport, 1986.

Heimann, A. and Ron, H., Geometric Changes of Plate Boundaries Along Part of the Northern Dead Sea Transform: Geochronologic and Palaeomagnetic Evidence, *Tectonics,* 1993, vol. 12, no. 2, pp. 477–491.

Heimann, A. and Steinitz, G., $^{49}Ar/^{39}Ar$ Total Gas Ages of Basalts from Notera 3 Well, Hula Valley, Dead Sea Rift: Stratigraphic and Tectonic Implications, *Isr. J. Earth Sci.,* 1989, vol. 38, pp. 173–184.

Horowitz, A., Neogene Palynostratigraphy, Paleoflora, and Paleoclimatic Reconstruction in Israel, *Paleobiol. Cont. Montpellier,* 1980, vol. XVII, pp. 245–257.

Husein, K.M. and Rybakova, N.O., The Results of Micropaleobotanical Studies of Neogene Deposits in the Al-Kebir River Basin (Syria), *Vestn. Mos. Gos. Univ., Ser. Geol.,* 1973, no.3, pp. 108–112.

Kopp, M.L., Abstracts of Papers, *Second International Symposium on the Geology of the Eastern Mediterranean Region,* Jerusalem, 1995.

Kopp, M.L., Leonov, Yu.G., and Adjamian, J., The Deformations in the Eastern Part of the Arabian Plate as a Result of Displacements Along the Levantine Fault, *Geotektonika,* 1994, no. 3, pp. 61–76.

Leonov, Yu.G., *Tectonics of Syria, Explanatory Notes to the Tectonic Map of Syria* (in press).

Novikov, V.M., Sharkov, E.V., Chernyshev, I.V., *et al.,* Geochronology of Weathering Crusts on Flood Basalts in Syria and the Evolution of Regional Paleoclimate during the Last 20 Ma, *Stratigr. Geol. Korrelyatsiya,* 1993, vol. 1, no. 1, pp. 66–74.

Papaianopol, I., L'etude des unionides du Romanien inferieur (Pliocene) de la zone des plis diapirs externes de Muntenia oriental (Bassin Dacique), in: *Mollusques et Ostracodes Neogenes,* Bucarest, 1989, pp. 5–55.

Ponikarov, V.P., Kaz'min, V.G., Kozlov, V.V., Krasheninnikov, V.A., *et al.,* Siriya, in *Geologiya i poleznye iskopaemye zarubezhnykh stran,* (Geology and Mineral Resources of Foreign Countries), Leningrad: Nedra, 1969, no. 18.

Schutt, H., Die Molluskenfauna der Süsswasser in Einzugsgebiet des Orontes unter Berücksichtigung benachbarter Fluss Systeme, *Arch. Mollusk.,* 1983, vol 113, no. 1/6, pp. 17–91.

Schutt, H, Ergaenzungen zur Kenntnis der Molluskenfauna oder Pliozaener Süsswasserkonglomerate Syriens, *Arch. Mollusk.,* 1988, vol. 118. no. 4/6, pp. 129–143.

Selli, R., Accorsi, J., *et al.,* The Vrica Section (Calabria, Italy): A Potential Neogene/Quaternary Boundary Stratotype, *Giornale di Geologia,* Bologna, 1977, vol. 1, no. 11, pp. 181–204.

Simakova, A.N., Palynology of the Marine Upper Pliocene in Syria and Paleogeographic Analysis, *Stratigr. Geol. Korrelyatsiya,* 1994, vol. 2, no. 2, pp. 96–102.

Shalin, G. and Steinitz, G., Dating of the Neogene Sequence at Kochav Hayarden, *Isr. Geol. Soc. Annu. Mtg.,* 1987.

Sharkov, E.V., Sindeev, A.S., Ali S., Hanna S., and Sharaf, M., Petrology of the Homs Basalt Area (Western Syria), *Izv. Akad. Nauk SSSR, Ser. Geol.,* 1987, no. 7, pp. 61–71.

Sharkov, E.V., Chernyshev, I.V., Devyatkin, E. V., Dodonov, A.E., *et al.*, Geochronology of the Late Cenozoic Basalts in Western Syria, *Petrologiya*, 1994, vol. 2, no. 4, pp. 439–448.

Steinitz, G., Bartov, J., and Hunziker, J., K–Ar Age Determination of Some Miocene–Pliocene Basalts in Israel: Their Significance to the Tectonics of the Rift Valley, *Geol. Mag.*, 1978, vol. 115, pp. 329–340.

Suc, J.P., La vegetation et le climat du Languedoc (Sud de France) en pliocene moyen d'apres la palynologie, *Paleobiol. Cont. Montpelier*, 1981, vol. XII, no. 1, pp. 7–26.

Trifonov, V.G., Trubikhin, V.M., Adjamyan, J., *et al.*, The Levantine Fault Zone in Northeastern Syria, *Geotektonika*, 1991, no. 2, pp. 63–75.

Van Liere, W.J., Observations on the Quaternary of Syria, *Berichten Rijksd. Oudheidk. Bodemonderzoek*, 1960–1961, nos. 10–11, pp. 7–69.

Willmann, R., Evolution, Systematik und stratigraphische Bedeutung der neogenen Süsswassergastropoden von Rhodos und Kos/Aegaeis., *Palaeontographica*, 1981, pt. A, vol. 174, issues 1–6, pp. 10–235.

Wilson, M., *Igneous Petrogenesis*, Boston: Unvin Hyman, 1989.

Stratigraphy and Geological Correlation, Vol. 5, No. 4, 1997, pp. 375–390. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 4, 1997, pp. 68–84.
Original Russian Text Copyright © 1997 by Velichkevich, Khursevich, Rylova, Litvinyuk.
English Translation Copyright © 1997 by MAIK Nauka/Interperiodica Publishing (Russia).

The Middle Pleistocene Stratigraphy of Belarus

F. Yu. Velichkevich, G. K. Khursevich, T. B. Rylova, and G. I. Litvinyuk

Institute of Geoscience, Belarussian Academy of Sciences, ul. Zhodinskaya 7, Minsk, 220141 Belarus

Received April 18, 1995

Abstract—The paper provides insight into the complex paleobotanical characteristics of three Pleistocene sections unknown before (Well 2G near the village of Borki, Well 6 near the village of Yatvez', and Well 3 near the village of Smolyarka) and correlated with other coeval sections of southwestern Belarus, Russia, Latvia, and Poland. The deposits studied were formed during the following periods: the Belovezh'e interglaciation and initial phases of the Nizhninskii glaciation in the Borki section; the Belovezh'e interglaciation, Nizhninskii glaciation, and Mogilev interglacial stage in the Yatvez' sequence; and the Belovezh'e interglaciation, Nizhninskii glaciation, Mogilev interglaciation, and incipient Berezina glaciation in the Smolyarka locality. The Belovezh'e, Nizhninskii, and Mogilev horizons of Belarus are correlated with several other units such as the Muchkap (Roslavl') Horizon of central Russia, the Zhidini Horizon of Latvia, and the Ferdynandow Horizon of Poland. In addition, the Berezina Horizon of Belarus is considered to be an equivalent of the Okaian Glaciohorizon of central Russia, Dainava Horizon of Latvia, and Vilga Horizon of Poland. In accordance with the new scheme of Pleistocene stratigraphy in Belarus (Velichkevich *et al.*, 1996), the four horizons mentioned above are referred to the middle Pleistocene, whose lower boundary is placed at the base of the oldest glacial deposits of the Narev Horizon, whereas the upper one is accepted marking the foot level of the Dnjeprian glacial beds.

Key words: *Pleistocene, horizon, section, stratigraphy, Belovezh'e interglaciation, flora, vegetation*

INTRODUCTION

The problem of occurrence of sedimentary formations constituting the interglacial Shklov Horizon and relations between this and Belovezh'e Horizon were keenly debatable in the Pleistocene stratigraphy of Belarus over the last 20 years. In the unified stratigraphic scheme of Quaternary deposits of Belarus accepted in 1982, the first horizon is placed between the Dnjeprian and Sozh glaciohorizons of the middle Pleistocene, whereas the last one separates the Narev and Berezina horizons of the lower Pleistocene. However, some geologists and paleontologists do not share this viewpoint.

For instance, Voznyachuk (1971, 1981, 1985) and his followers (Velichkevich, 1982; Kondratene and San'ko, 1985; and others) state that Belovezh'e beds and deposits of the "lower (Lyuban' or Glazovo) optimum" of the Shklov interglaciation are coeval, having identical spore–pollen diagrams and composition of extinct species and displaying similar evolutionary levels of leading representatives of fauna and flora. As for sedimentary beds corresponding to the intervening cooling and "second optimum" of the Shklov interglacial stage in the Nizhninskii Rov section at the Dnieper River, Voznyachuk (1981) identified them in his stratigraphic scheme as individual units (Nizhninskii Stade and Mogilev Interstade respectively) and placed them together with the Belovezh'e Horizon in the lower Pleistocene below the Berezina (Okaian) Horizon. The scheme of Voznyachuk was based at that moment on limited paleontological data. Over the next 10–15 years, the stratigraphic positions of these horizons were refined and substantiated by new paleontological materials obtained by the check drilling in the Shklov, Borki, Rechitsa, and Bereza stratotype areas of Belarus, and many relevant data have already been published (Makhnach *et al.*, 1982; Makhnach and Rylova, 1986; Khursevich and Loginova, 1986; Yakubovskaya, 1986; Goretskii *et al.*, 1987; Yakubovskaya *et al.*, 1991; Velichkevich *et al.*, 1993; and others).

In this work, we summarize biostratigraphic data for three new wells drilled in southwestern Belarus in order to show how these sections can be correlated with coeval deposits in neighboring regions.

RESULTS

Borki Section in the Belovezhskaya Pushcha

In the depth interval of 87.0–100.5 m, Well 153, which was drilled in the late 1950 at the eastern end of the village of Borki, Pruzhany district of the Brest region, recovered a sequence of lacustrine deposits, mainly of the carbonate gyttja type, which were first studied by Voznyachuk, Puzanov, Manykin, and others. Using spore–pollen data, Kobets and Voznyachuk suggested the interglacial origin of these deposits and referred them to the Belovezh'e interglaciation of Belarus, which was correlated at that time with the

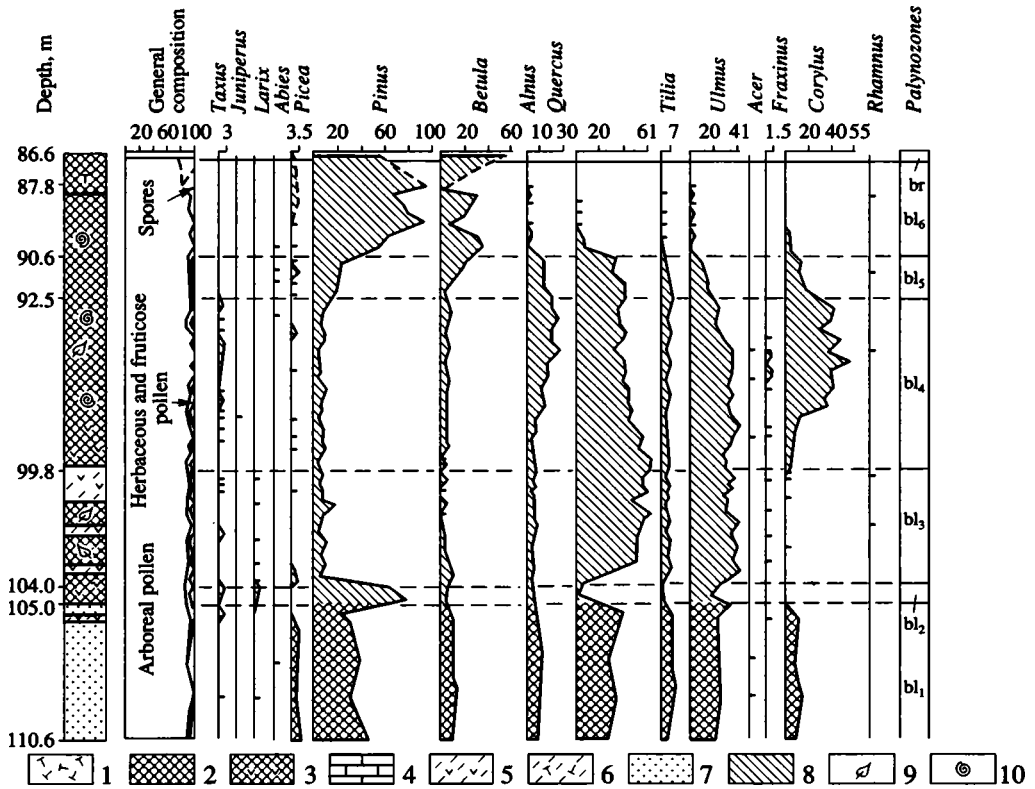


Fig. 1. Palynological diagram for the Pleistocene lacustrine deposits recovered by Well 2G near the village of Borki: (1) peat; (2) gyttja; (3) diatomaceous gyttja; (4) sapropelite; (5) diatomaceous sandy loam; (6) peat–sandy loam; (7) sand; (8) loam; (9) plant remains; (10) mollusks.

Cromerian of western Europe. Another viewpoint of a later period (Makhnach, 1971; Gurskii, 1974; Goretskii, 1980; and others) assumes the interglacial beds of the Borki section corresponding to the Shklov (post-Likhvinian, or second in the middle Pleistocene) interglaciation, and this stimulated scientists to reexamine this section in detail. The check drilling near the Borki stratotype, aimed to refine the stratigraphic position of interglacial deposits and to complete their paleontological characteristics, was performed twice, first in 1980 at the site of Well 2, located 18 m northwestward of Well 153, and then in 1989 at the site of Well 2G, 33 m away to the northeast from the original well. Well 2G, whose section is selected as the neostratotype of the Belovezh'e interglaciation (Yakubovskaya *et al.*, 1991; Velichkevich *et al.*, 1996), yielded the most representative paleobotanical data.

Palynological diagrams characterizing a depth interval of 86, 60–105.0 m in Well 2G near the village of Borki (Fig. 1) allow us to gain insight into the evolution of regional vegetation throughout the Belovezh'e interglaciation, beginning from the climatic optimum and up to the transition to the glaciation stage. Core samples from the interval of 105.0–110.6 m are of a poor quality, and fine- to medium-grained sands recovered from here bear abundant, though unsatisfactorily preserved pollen grains of broad-leaved plants, *Pinus*, *Alnus*, and *Juglans* associated with spores of *Selaginella selaginoides* (L.) Lk., which seem to be a result of down-hole contamination. A thin interlayer of peaty–sandy loam (depth interval of 105.8–105.9 m) yielded pollen and spores of Neogene plants. Samples above the depth of 105.0 m contain abundant and well preserved pollen and spores, whose composition regularly changes upward the section. This provided an opportunity to distinguish six pollen zones corresponding to concrete phases of plant evolution during the Belovezh'e interglaciation (palynozones bl_2–bl_6) and subsequent glaciation stage (palynozone nz). These phases are:

bl_2 (depth interval of 104.0–105.0 m)—the phase of pine forests with admixture of birch, alder, larch, spruce, and broad-leaved trees (*Pinus* = 79[1], *Betula* = 3.5, *Alnus* = 1.5, *Quercus* = 4, *Ulmus* = 6, *Picea* = 0.5, *Larix* = 1, *Taxus* = 1%);

bl_3 (depth interval of 99.8–104.0 m)—the phase of broad-leaved (oak, elm, linden) forests with admixture of pine, birch, and alder (*Quercus* = 61, *Ulmus* = 40, *Tilia* = 5, *Pinus* = 20%);

[1] From here on, figures indicate the maximum content in %.

bl_4 (depth interval of 92.5–99.8 m)—the phase of broad-leaved (oak, elm, linden, maple, ash) forests with accessory pine, birch, and alder trees and well developed hazel undergrowth (*Quercus* = 60, *Ulmus* = 41, *Tilia* = 7, *Fraxinus* = 1.5, *Acer* = 0.5, *Alnus* = 27, *Corylus* = 55%);

bl_5 (depth interval of 90.6–92.5 m)—the phase of broad-leaved–coniferous (pine, spruce, fir) forests with alder and hazel boscage (*Quercus* = 34, *Ulmus* = 14, *Tilia* = 6, *Corylus* = 16, *Pinus* = 24, *Betula* = 18, *Abies* = 0.5, *Picea* = 3.5%);

bl_6 (depth interval of 87.85–90.6 m)—the phase of coniferous (pine) and coniferous–birch forests with accessory broad-leaved plants and hazel boscage (*Pinus* = 95, *Betula* = 37, *Picea* = 3.5, *Juniperus* = 0.5%).

Upwards of the section, in the peaty gyttja bed (depth interval of 87.10–87.85 m), pollen is almost lacking, and only the two uppermost samples (depth interval of 86.6–87.1 m) yielded rather abundant pollen grains (23%) of herbaceous, such as Poaceae, Cyperaceae, *Artemisia*, Ranunculaceae (including *Thalictrum*), and others, associated with *Betula* pollen (up to 60%). Pollen of the last taxon shows a tendency to be more abundant upward, and specimens of *Betula* sect. *Fruticosae* represent 12% in its composition. We also recorded a decreased amount of *Pinus* pollen and the presence of *Picea* specimens (3.5%). This kind of spectra corresponds to the phase of birch and birch–pine forests with rather abundant herbaceous plants indicating the beginning of the Nizhninskii glaciation.

According to the data of Yakubovskaya, carpogenous flora from Wells 2 and 2G of the Borki locality includes an indicative group of arboreal and fruticose plants: *Picea* sp., *Larix* cf. *decidua* Mill., *Pinus sylvestris* L., *Betula alba* L., *B. pendula* Roth., *B. humilis* Schrank, *Betula* sp., *B.* cf. *nana* L., *Alnus* sp. exot., *Tilia* cf. *tomentosa* Moench., and *Acer* sp. Another group characteristic of the early Pleistocene of Belarus is represented by exotic herbaceous, such as *Caulinia* ex. gr. *tenuissima* A. Br., *Stratiotes* cf. *intermedius* (Hartz) Chandl., *Scirpus atroviroides* Dorof., *Carex pauciflor-oides* Wieliczk., *Nymphaea cinerea* Wieliczk., *N.* cf. *pusilla* Dorof., *Ranunculus sceleratoides* Nikit. et Dorof., and *Hypericum pleistocenicum* Wieliczk. The characteristic group of plants dominant in taphocoenoses (more than 10 specimens) includes *Salvinia natans* (L.) All., *Picea* ex sect. *Piceae*, *Typha* cf. *latifolia* L., *Potamogeton vaginatus* Turcz., *P. perfoliatus* L., *Najas marina* L., *Caulinia minor* (All.) Coss. et Germ., *Stratiotes* cf. *intermedius* (Hartz) Chandl., *Betula alba* L., *Rumex maritimus* L., *Nuphar lutea* (L.) Smith, *Ranunculus sceleratus* L., *R. sceleratoides* Nikit. et Dorof., *Hippuris vulgaris* L., and *Menyanthes trifoliata* L. Both the arboreal and characteristic herbaceous plants do not include species exclusively typical of the Belovezh'e interglaciation of Belarus, and this sometimes precludes stratification of heterochronous carpogeneous floras of the middle Pleistocene. Nevertheless, the distribution of carpolites in sections of Wells 2 and 2G of the Borki locality distinctly marks intervals of deposits concentrating all thermophilic and extinct exotic forms depicting the interglacial optimum.

Diatoms are recovered from Well 2G at a depth of 97.6–105.4 and 96 m (Fig. 2). This flora consists of 144 specific and intraspecific taxa. Persistently dominant in the section are planktonic species of the *Cyclotella* genus, indicating deposition of sediments in a moderately deep and weakly oligotrophic basin notably enriched in carbonate components. Taxa from the interglacial deposits (phases Ia–Ic of the diatom evolution) include the following species: *Cyclotella reczickiae* Churs. et Log. var. *reczickiae* (up to 7.6%), known at present only from the Belovezh'e beds and representing the index species of the flora studied; *C. reczickiae* var. *diversa* Log. (up to 45.6%) first discovered in the Belovezh'e flora, but also recorded in relic floras of the Aleksandriya (Likhvinian) and Murava (Mikulinian) interglaciations; *C. radiosa* var. *pliocaenica* (Krasske) Häkansson (8%) and *C. radiosa* var. *lichvinensis* (Jous) Log. (up to 25%), the relic Pliocene forms vanished before the end of Pleistocene; *C. radiosa* (Grun.) Lemm. var. *radiosa* (up to 35%), *C. cyclopuncta* Häkansson et Carter (28–35%), *C. distinguenda* Hust. (11–18%), and *C. krammeri* Häkansson (up to 7%), all representing species of a wide stratigraphic range (from the Miocene to present time). Species of *Navicula* genus, such as *N. hasta* Pant., *N. lanceolata* (Ag.) Kütz., *N. oblonga* Kütz., *N. reinhardtii* (Grun.) Cl., and others, are the most diverse among benthic forms, whereas *Amphora ovalis* Kütz. (up to 6.6%) and *A. libyca* Ehr. (up to 7.6%) are the most abundant among them. Some fouling forms of *Fragilaria, Cymbella, Gomphonema*, and other genera are insignificant in the composition of the diatom flora.

Thus, data obtained by the check drilling considerably supplemented the paleontological characteristics of the interglacial Belovezh'e Horizon in the holostratotype area. They prove that this unit is older than the Berezina (Okaian) Horizon, and therefore Voznyachuk's stratigraphic concept appears to be correct.

Yatvez' Section

Thick (over 20 m) lacustrine deposits of the Belovezh'e time dated by spore–pollen and diatom analyses (Rylova and Khursevich, 1989) were recovered in the mid–1980s by Well 1885, located 3.9 km southwestward of the village of Yatvez', Ivatsevichi district of the Brest region. A new well of key stratigraphic significance was drilled in 1993 not far from the previous wellhead. This well penetrated through the following beds (figures in parentheses indicate the basal depth level of every bed):

1. soil (0.15 m);

2. yellowish brown sand of variable grain size with sporadic gravel (5.0 m);

3. yellowish gray loam (6.0 m);
4. gray fine-grained sand with a silt interbed (11.0 m);
5. mixed sand and gravel (25.0 m);
6. unit gIIbr: red-brown morainal loam (26.5 m);
7. gray fine-grained sand (34.0 m);
8. blue-gray fine-grained and horizontally layered sand (39.0 m);
9. gray fine-grained sand with silt interbeds (44.0 m);
10. blue-gray layered silt (49.0 m);
11. unit lIIbr: sand of variable grain size with sporadic pebble and gravel inclusions (52.0 m);
12. unit lIImh: dark gray to black sandy loam, sometimes peaty (53 m);
13. unit lIImh: dark gray, slightly brownish gyttja (55.0 m);
14. unit lIInz: brown and dense peaty–sandy loam (60.0 m);
15. unit lIIbl: brownish gray, chipping and layered gyttja (62.7 m);
16. unit lIIbl: gray laminated sapropelite (75.5 m);
17. unit lIIbl: blue-gray, horizontally layered silt (81.0 m);
18. unit lIIja: fine- to medium-grained sand with rare plant remains (100 m).

Spore–pollen analysis was applied to 158 samples collected from the depth interval of 44.0–81.0 m. In the depth interval of 60.2–75.5 m, spores and pollen are abundant and well preserved, whereas above and below it pollen grains are extremely rare. The diagram obtained (Fig. 3) depicts eight palynozones characterizing the entire evolutionary cycle of vegetation during the Belovezh'e interglaciation in contrast to the diagram for Well 1885, which illustrated only an upper part of the climatic optimum and post-optimum phases (Rylova and Khursevich, 1989).

Palynozone bl_1 (depth interval of 74.8–75.5 m) yielded predominantly pollen grains of *Betula* (64%) and *Pinus* (50%) reflecting development of birch–pine assemblages at the beginning of the interglacial stage.

Palynozone bl_2 (depth interval of 74.5–74.8 m) marks the association of dominant *Pinus* pollen (69%) with less abundant specimens of *Betula* (21%), *Quercus* (7%), *Ulmus* (3%), and *Alnus* (1%), which indicates an admixture of broad-leaved taxa to the pine–birch forests.

Palynozone bl_3 (depth interval of 73.5–74.5 m) is distinguished due to the considerably increased content of pollen of broad-leaves *Quercus* (23%), *Ulmus* (13%), and *Tilia* (2%), whereas *Pinus* and *Betula* become less significant here. This spectrum corresponds to the time of broad-leaved–coniferous assemblages with accessory birch and alder specimens.

Palynozone bl_4 (depth interval of 69.7–73.5 m) shows concentration maxima of broad-leaved *Ulmus* (33%), *Quercus* (28%), and *Tilia* (11%), peak abundances of *Corylus* (64%) and *Alnus* (27%), minimum

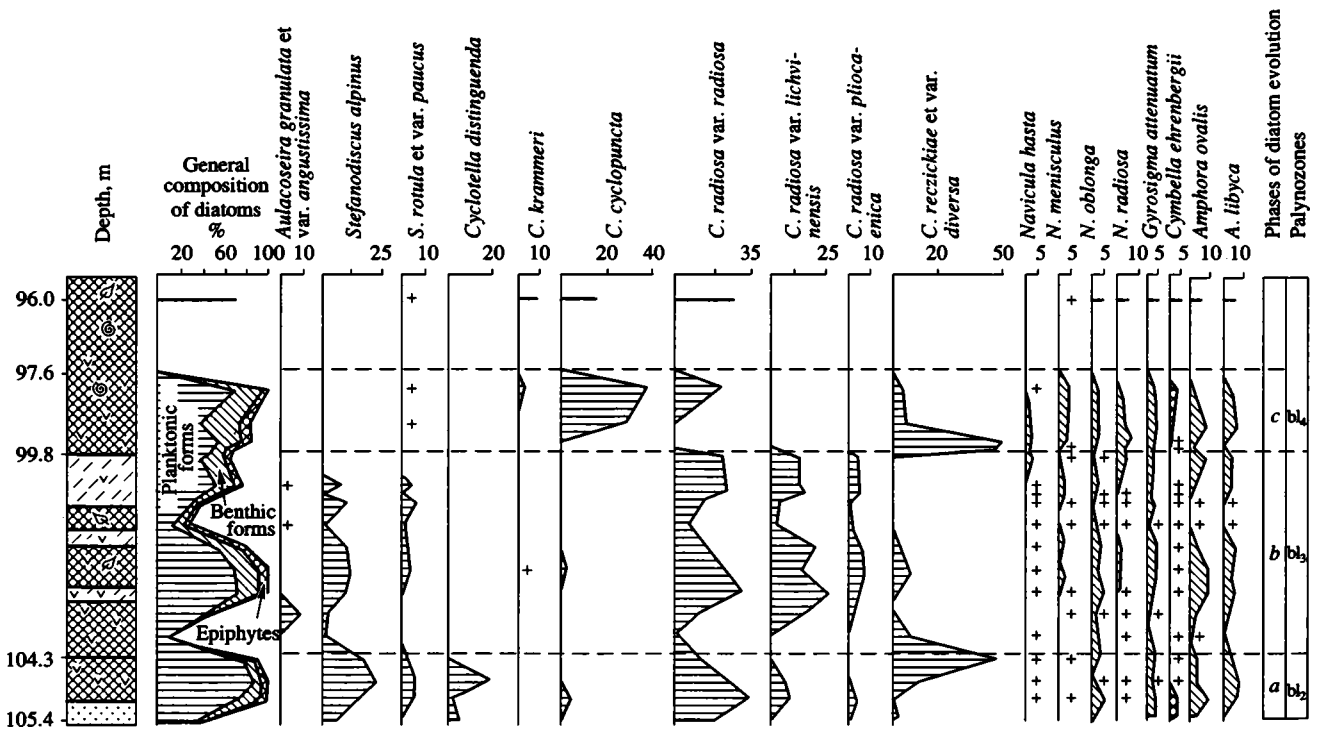


Fig. 2. Distribution of diatoms in the Belovezh'e interglacial deposits recovered by Well 2G near the village of Borki (symbols as in Fig. 1).

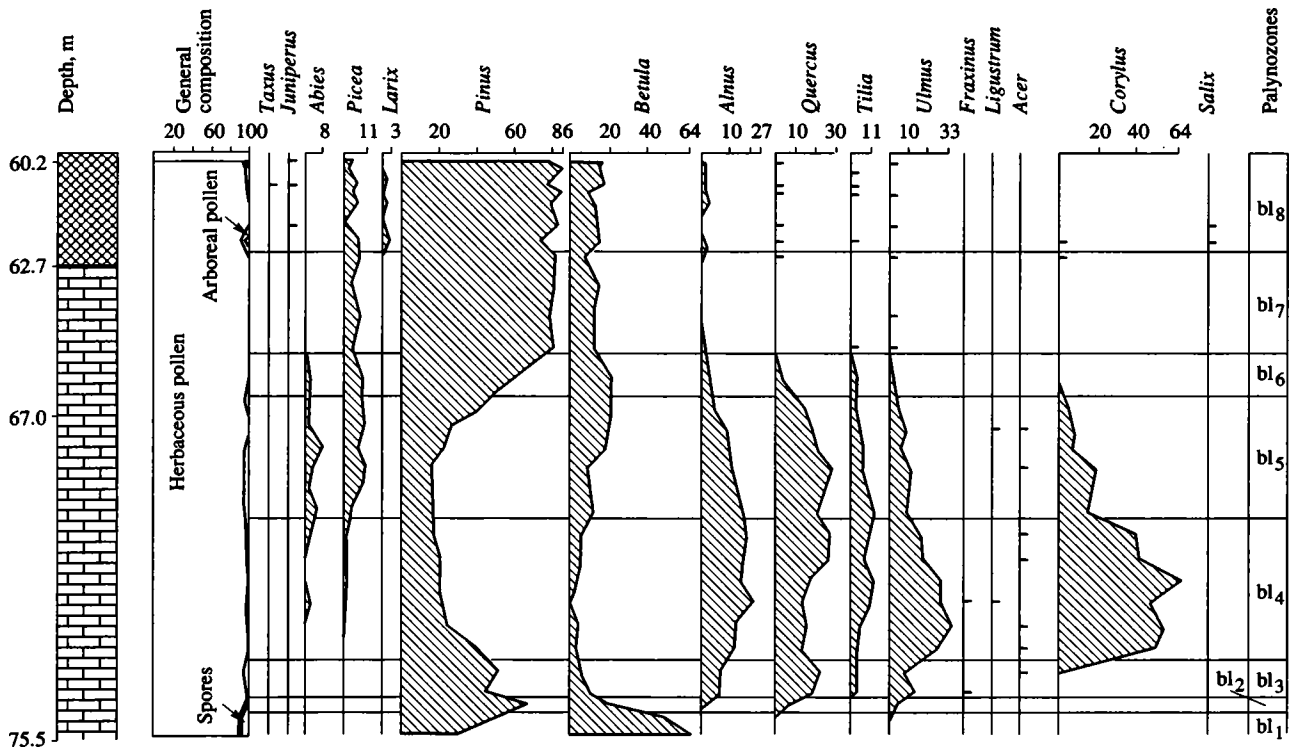


Fig. 3. Palynological diagram for the Belovezh'e interglacial deposits recovered by Well 6 near the village of Yatvez' (symbols as in Fig. 1).

contents of *Abies* and *Pinus* specimens, and the appearance of *Picea*. This indicates the predominance of broad-leaved taxa in the forest vegetation, which also incorporated dark conifers, hazel, and alder.

Palynozone bl_5 (depth interval of 66.5–69.7 m) has a rather high, but steadily decreasing content of *Quercus* (30%), *Ulmus* (10%), *Tilia* (11%), *Corylus* (18%), and *Alnus* (22%), whereas proportions of *Betula* (22%) and dark conifers, such as *Abies* (8%) and *Picea* (11%), gradually increase here. This spectrum suggests vegetation that included the broad-leaved–spruce–fur assemblage with subordinate pine, birch, hazel, and alder, the last taxon residing in humid areas.

In palynozone bl_6 (depth interval of 65.5–66.5 m), we noted that *Quercus* (2%), *Tilia* (2%), *Ulmus* (2%), and *Abies* (1.5%) sharply decrease in abundance. *Betula* (20%) and *Alnus* (3%) are also less abundant here; pollen of *Corylus* is totally missing, while pollen of *Pinus* (60%) is, on the contrary, the main component of the spectrum. Such a spectrum implies a wide distribution of conifers associated with birch trees and some broad-leaved taxa.

Palynozone bl_7 (depth interval of 62.4–65.5 m) is very rich in pollen of *Pinus* (82%), but shows a lesser content of *Picea* (8%) and *Betula* (15%) pollen. It is almost lacking broad-leaved forms, *Corylus*, and *Alnus*, whose pollen occurs as scarce grains. Palynospectra from this part of the section reflect simple composition of coniferous–broad-leaved forests suggesting a period of climatic cooling.

Palynozone bl_8 (depth interval of 60.2–62.4 m) is the occurrence level of *Larix* (3%), *Juniperus*, *Betula humilis* Schrank, and *Salix* (single grains). Pollen of herbaceous plants becomes abundant here, and this can be considered as an indicator of open landscapes, which disturbed the formerly massive forests.

Thus, spore–pollen data newly obtained from the ancient lacustrine deposits of the Yatvez' section display the most complete succession of vegetation that was typical of the Belovezh'e time in Belarus.

Diatomaceous flora from Well 6 is confined to the depth interval of 53.0–74.3 m. It includes 192 specific and intraspecific taxa. Variations in the abundance and composition of diatoms from the base upward the section reveal three periods (with 11 phases) of their evolution (Fig. 4), which are well compatible with the results of palynological and carpological studies.

The first period in the evolution of diatoms during the interglaciation (depth interval of 60.2–74.3 m) is divided into seven phases (Ia–Ig). Phases Ia and Ib correspond to the incipient phases of interglaciation optimum and point to weakly oligotrophic conditions in the past water basin. The basin was initially populated by planktonic *Cyclotella radiosa* (Grun.) Lemm. and its varieties (up to 33%), but afterward they gave way to *C. reczickiae* var. *diversa* Log (up to 37%), the taxon

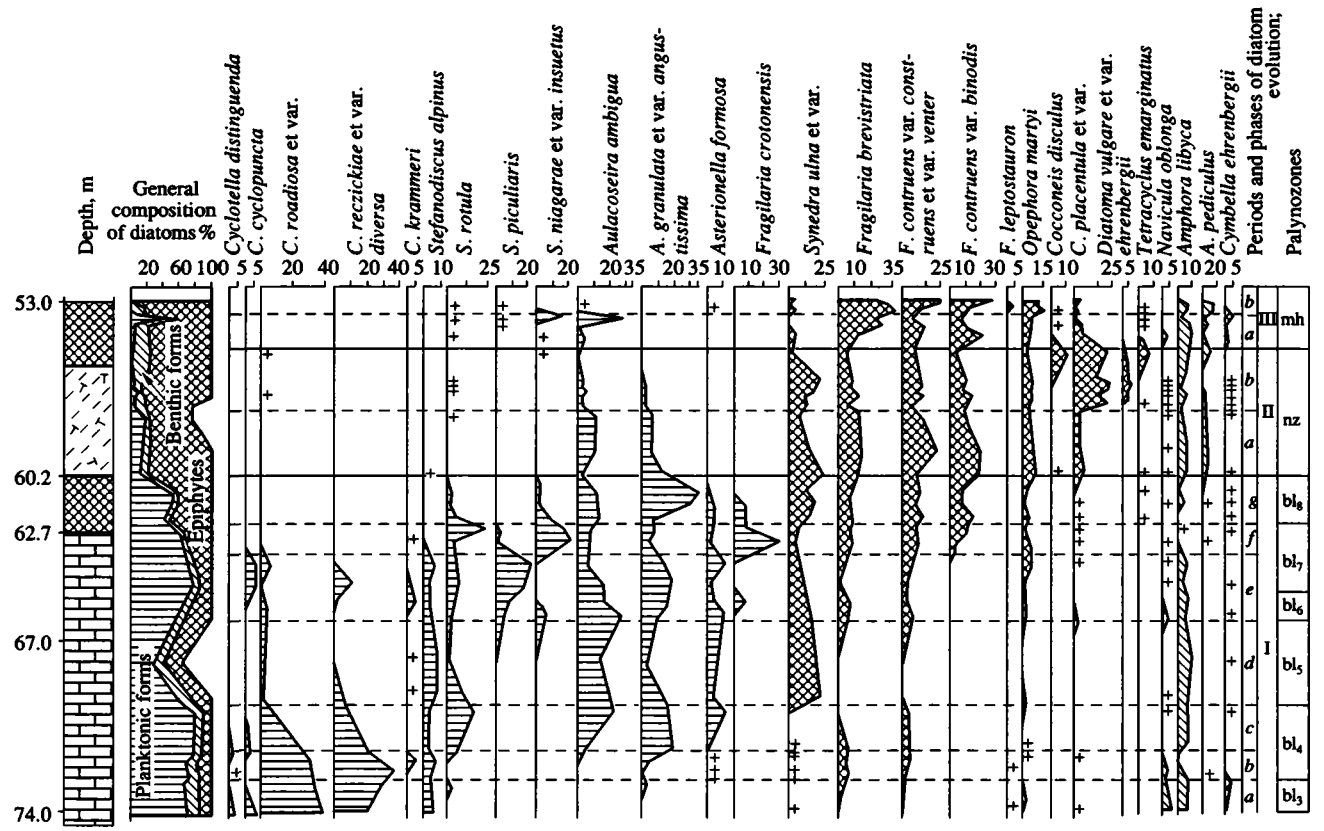


Fig. 4. Distribution of diatoms in the Pleistocene deposits recovered by Well 6 near the village of Yatvez' (symbols as in Fig. 1).

that became extinct in the Pleistocene. Benthic and periphyton representatives had an insignificant role in the flora composition. Later, when the climate became warmer in the mid-optimum time (phase Ic), the initially dominant *Cyclotella* species were replaced by moderately thermophilic and eurythermic planktonic forms, such as *Aulacoseira granulata* (Ehr.) Sim. and its subspecies (up to 18.7%), *A, ambigua* (Grun.) Sim. (up to 21.8%), *Stephanodiscus rotula* (Kütz.) Hendey (16.4%), and *Asterionella formosa* Hassal (10.2%), which are indicators of the eutrophic state of the ancient lake. At the end of the optimum (phase Ie), leading diatom forms were represented by *Aulacoseira ambigua* (Grun.) Sim. (14–27%) in plankton, *Amphora libyca* Ehr. (5.8–7.0%) in benthos, and *Synedra ulna* (Nitzsch.) Ehr. (up to 17.6%) in periphyton. The post-optimum time (phases Ie and If) is marked again by changes in composition of diatoms, whose population became enriched in planktonic species. Phase Ie marks the peak abundance (18.3–21.1%) of *Stephanodiscus peculiaris* Churs., the species that ceased to live in the Pleistocene. An insignificant growth in abundance was also typical of *Cyclotella* species, including their Pliocene relic *C. radiosa* var. *pliocaenica* (Krasske) Häkansson (5.3%) typical of the Belovezh'e Interglacial, and the extinct Pleistocene species *C. reczickiae* var. *diversa* Log. (11.3%). *Stephanodiscus niagarae* var. *insuetus* Churs. et log. (20.5%), the taxon that died out before the end of the middle Pleistocene, and the widespread boreal species *Fragilaria crotonensis* Kitt. of the true planktonic type (up to 31.7%) prevailed at the beginning of Phase If, but afterwards the peak abundance was characteristic of *Stephanodiscus rotula* (Kütz.) Hendey (24.1%).

At the end of the interglaciation (Phase Ig), many planktonic forms disappeared from the diatom flora because of the paleobasin regression and deteriorated physical and geographic conditions in the watershed area of the basin. The principal elements of this flora were representatives of the *Aulacoseira* genus, which associated with widespread littoral epiphytes of *Synedra* and *Fragilaria* genera, whose abundance became considerably greater.

In the next period of evolution (depth interval of 55.0–60.2 m) divided into phases IIa and IIb, the diatom flora was different in composition. Phase IIa corresponds to the mass abundance of littoral *Fragilaria* species coexisting with accessory *Aulacoseira* forms. Phase IIb marks the peak abundance of boreal epiphytes *Cocconeis placentula* Ehr. (up to 21%) and moderately cryophilic *Cocconeis disculus* (Schum.) Cl. (6.7%), *Tetracyclus emarginatus* (Ehr.) W. Sm. (6.5%), *Diatoma vulgare* var. *ehrenbergii* (Kütz.) Grun. (5.5%), *Cymbella aspera* (Ehr.) Cl. (1.5%), and some other

forms. This diatom assemblage suggests a low temperature and shallow depth of the paleobasin that existed at the time of climatic cooling after the Belovezh'e Interglacial, i.e., during the Nizhninskii glacial stage.

Finally, the third period of diatom evolution (depth interval of 53–55 m) suggests a new improvement of ecological conditions in the paleolake, which again became populated (Phase IIIa) by moderately thermophilic planktonic forms, such as *Aulacoseira ambigua* (Grun.) Sim. (31.6%) and *Stephanodiscus niagarae* Ehr. (17.4%), and by benthic species of the *Navicula, Amphora, Cymatopleura, Surirella*, and other genera. The *Fragilaria* species remained rather abundant, and their representatives became prevailing (54.6–73.5%) during Phase IIIb. At this time, the epiphyte *Opephora martyi* Herib. (up to 15.2%) and benthic form *Amphora pediculus* Kütz. (up to 8%) were also the leading elements. Despite its incomplete characteristic, the last evolutionary period of diatom flora definitely corresponds to the new climatic warming most likely compatible with the Mogilev interglaciation.

Beds in the depth interval of 75.5–52.0 m almost identical to that bearing the diatom flora were also studied with respect to their carpological characteristics. According to Litvinyuk (see in Khursevich *et al.*, 1994), the evolution of paludous and riparian flora, which consisted of arboreal, fruticose, and herbaceous plants, is divisible into three stages. The first one, corresponding to beds with spores, pollen and diatoms typical of the Belovezh'e Interglacial (depth interval of 75.5–60.5 m), is represented by a limited number of taxa, like in other carbonate sediments of voluminous basins, which are usually not rich in carpolites. Arboreal and fruticose taxa established in these beds are *Pinus, Picea* sect. *Picea, Betula alba* L., *B. humilis* Schrank, *Corylus, Alnus glutinosa* (L.) Gaertn., *Swida sanquinea* (L.) Opiz, *Acer campestre* L., and very important leaf imprints of *Quercus* sp. in the middle sapropelite strata. This coexistence of conifers and nemoral elements of forest communities is typical of interglacial floras of the *"Quercus"* type, including the Belovezh'e flora. Herbaceous plants are represented here by widespread taxa of the temperate climate characterizing each and every interglacial assemblage: *Najas marina* L., *Caulinia minor* (All.) Coss. et Germ., *Carex* spp., *Urtica dioica* L., *Rumex maritimus* L., *Nuphar lutea* (L.) Smith, *Ceratophyllum demersum* L., *Comarum palustre* L., and *Menyanthes trifoliata* L. This assemblage does not point directly to the Belovezh'e age of the beds enclosing it; however, its interglacial type is beyond any doubt.

The second stage in the evolution of paludous and terrestrial macrophytes is marked by the carpolite assemblage from the depth interval of 60.0–57.8 m corresponding to the second evolutionary stage of the diatom flora (depth interval of 60.3–55.0 m). As compared to the previous vegetation, this flora is different in diversity and abundance of taxa. Its diversity increased due to the appearance of some usual eurythermic forms [*Potamogeton perfoliatus* L., *P. alpinus* Balb., *P. rutilus* Wolfg., *P. pusillus* L., *Rorippa palustris* (L.) Bess., *Cicuta virosa* L., and *Bidens cernua* L.] and exotic species (*Potamogeton perforatus* Wieliczk. and *Ranunculus sceleratoides* Dorof. ex Nikit.) despite the extinction of broad-leaved taxa, fruticose forms, and even *Alnus glutinosa* (L.) Gaertn. At the same time, *Betula humilis* Schrank, resistant against cooling, and especially *B. alba* L. became more abundant and dispersed in all deposits of the interval, where the relatively thermophilic taxa of the previous assemblage [*Najas marina* L., *Ceratophyllum demersum* L., and *Nuphar lutea* (L.) Smith] are missing.

The third period in the history of the hydro- and hygrophyte flora in question is illustrated by the carpological assemblage obtained from the depth interval of 57.8–52.0 m. At this level, the vegetal community is again of the interglacial type being represented by the *Brasenia* assemblage [*Brasenia* sp., *Nymphaea candida* J. et C. Presl., *Salvinia natans* (L.) All., and *Stratiotes* sp.] is usually associated with moderately thermophilic and mesophilic species, such as *Sparganium emersum* Rehm., *Potamogeton natans* L., *P. obtusifolius* Mert. et Koch, *P. compressus* L., *Najas marina* L., *Scirpus lacustris* L., *Cyperus fuscus* L., *Ceratophyllum demersum* L., *Ranunculus sceleratoides* L., *R. lingua* L., *Thalictrum* cf. *lucidum* L., *Empetrum nigrum* L., *Viola* sp., *Lycopus europaeus* L., *Mentha arvensis* L., and others. Flora from this part of the section shows the maximum taxonomic diversity and includes not only contemporary, but also extinct species characteristic of the middle Pleistocene interglaciations, namely *Potamogeton perforatus* Wieliczk., *Carex paucifloroides* Wieliczk., and *Ranunculus sceleratoides* Dorof. ex Nikit.

Thus, data on carpolites from the flora-bearing beds of the Yatvez' section are concordant with results of spore–pollen and diatom analyses. All the data demonstrate that the main part of the analyzed lacustrine sediments (about 15 m in thickness) corresponds to the Belovezh'e interglacial deposits underlying a bed whose flora reflects a period of climatic cooling (a minor glaciation?). In its turn, this bed is overlain by sediments bearing the fragmentary diatom flora and carpological remains of the next (Mogilev, Vitebsk) interglaciation.

Smolyarka Section

Interglacial deposits near the village of Smolyarka, Bereza district of the Brest region, were first penetrated by Well 13 in 1983. On the basis of spore–pollen (Rylova, 1985) and carpological (Velichkevich, 1985) data, they were classified as sediments of the Belovezh'e interglaciation, although Rylova believed that a peculiar pollen assemblage from the lower beds of the section may correspond to the older Korchevo interglaciation. The check drilling was performed here

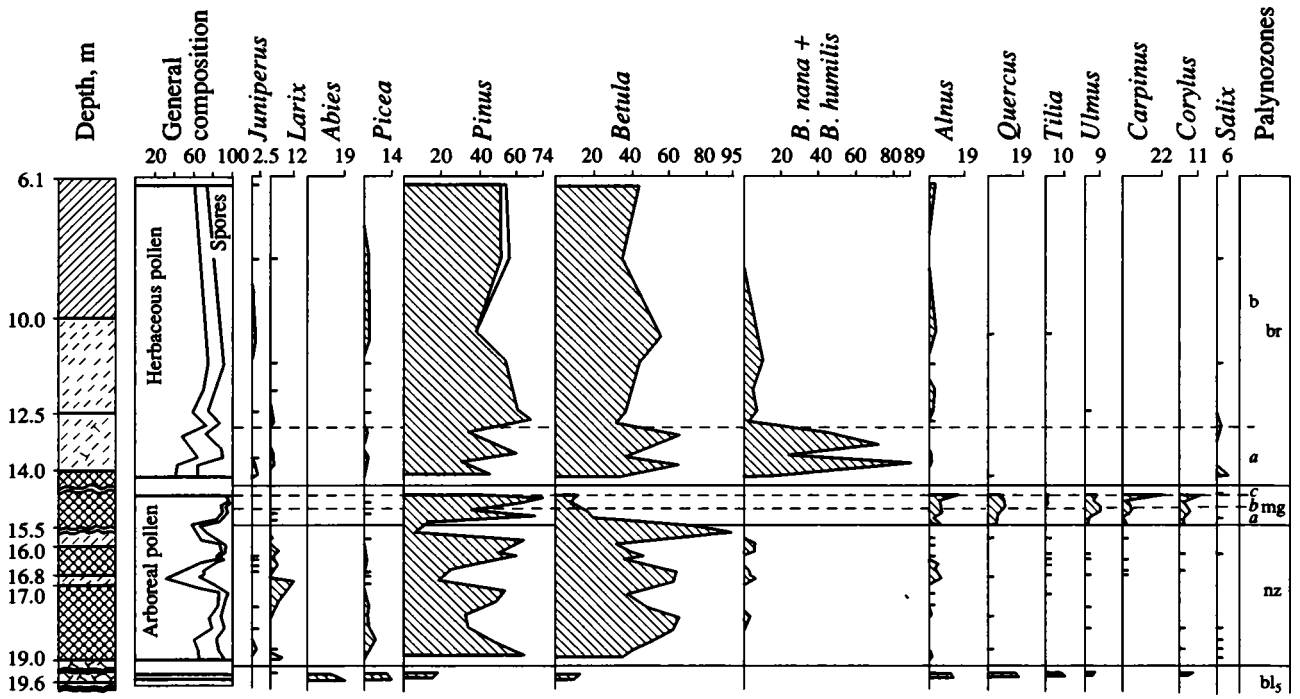


Fig. 5. Palynological diagram for the Pleistocene deposits recovered by Well 3 near the village of Smolyarka (symbols as in Fig. 1).

in 1993 and provided new data enabling another interpretation. In contrast to Well 13, which penetrated interglacial deposits soon below the surface (depth interval of 4.0–21.2 m) under the fine-grained sand (Velichkevich *et al.*, 1993), the new well recovered a thin moraine (depth interval of 2.0–6.1 m) presumably deposited by the Berezina glaciation and the underlying three-member bed sequence bearing flora and representing, similar to the Yatvez' section, two interglacial units separated by periglacial deposits. The sequence of beds penetrated by Well 3 is as follows:

1. soil (0.2 m);

2. unit vIIIpz: yellowish gray fine-grained sand (2.0 m);

3. unit gIIbr: greenish gray morainal sandy loam (6.1 m);

4. unit IIIbr: dark gray loam (10.0 m);

5. unit IIIbr: dark gray sandy loam with brownish tint (12.5 m);

6. unit IIIbr: gray sandy loam with peaty lenses and interbeds (14.0 m);

7. unit IIImg: dark brown peaty gyttja (15.5 m);

8. unit IIInz: light gray, locally humified sandy loam (16.0 m);

9. unit IIInz: dark brown to black gyttja, loamlike at the base (16.8 m);

10. unit IIInz: dense brownish gray sandy loam with horizontal bedding (17.0 m);

11. unit IIInz: dark gray layered gyttja (19.0 m);

12. unit bIIbl: dense paper peat of the *Carex–Hypnum* type (19.6 m);

13. unit IIIja: alternating fine-grained sand and dense sandy loam blue-gray in color (20.5 m);

14. unit IIIja: gray sand of variable grain size (22.0 m);

15. unit gIIja: gray morainal sandy loam enclosing the 1.5-m-thick interbed of blue-gray loam (35.0 m);

16. unit gIIja: mixed sand and gravel (42.0 m).

Under these beds, there is the Eopleistocene sequence of silt, clay, and sand, which grade downward into the Neogene deposits below the depth level of 71.5 m.

The spore–pollen diagram presented here (Fig. 5) depicts analytical results for 77 samples selected from the depth interval of 6.1–20.5 m.

Pollen and spores from the lower interglacial bed of peat (depth interval of 19.0–19.6 m) represent flora characteristic of the climatic optimum. The dominant components among them (99–99.5%) are dark coniferous and broad-leaved taxa, such as *Abies* (19%), *Picea* (14%), *Quercus* (19%), *Tilia* (10%), *Ulmus* (7%), *Corylus* (9%), *Alnus* (12%), *Pinus* (17%), and *Betula* (13%). This spectrum presumably corresponds to the Phase bl_5 of the Belovezh'e interglaciation, when flora corresponded to broad-leaved–spruce–fir forests with hazel–alder undergrowth in humid areas. The complete sequence of respective interglacial beds was earlier recovered by Well 13 (Velichkevich *et al.*, 1993). A high content of fir and spruce pollen visible in the diagram for Well 3 is also characteristic of coeval beds in wells 6 and 1885 of the Yatvez' locality in the Iva-

tsevichi district and thus represents the regional feature of the Belovezh'e Interglacial in southwestern Belarus.

Samples from the higher interval of 15.6–19.1 m yielded spectra whose composition points to severe climatic conditions of the subsequent glacial stage. This interval is considerably depleted in the arboreal pollen, which constitutes only 15–20% in some samples; however, it is enriched in the herbaceous pollen (up to 35%) and spores (also up to 35%). The assemblage of arboreal pollen predominantly consists of *Betula* species, including up to 95% of *B. nana* L. and *B. humilis* Schrank, and also contains rather abundant grains of *Larix* (12). We may assume therefore that the area in question was lacking dense forests at that time and comprised widespread open landscapes. The mixed pollen assemblage of forest, steppe, and tundra taxa reflects peculiar groupings of plants in the periglacial area under consideration.

The next gyttja bed in the interval of 14.5–15.6 m shows a considerable change in the pollen composition. The broad-leaved taxa, such as *Quercus* (10), *Tilia* (2,5), *Ulmus* (9), and *Carpinus* (22), coexist here with *Corylus* (11), *Alnus* (19), and rare representatives of *Acer, Vitis* and *Pterocarya* against the background of rather abundant *Pinus* pollen always mixed with *Betula* specimens. The interval can be divided into three pollen zones: (a) a zone of dominant *Quercus* and *Ulmus* mixed with *Carpinus, Acer, Corylus*, and *Alnus*; (b) a zone of the first occurrence of *Tilia* specimens; and (c) a zone of abundant *Carpinus* pollen simultaneously enriched in such taxa as *Corylus, Alnus*, and *Tilia*. The last zone also marks the minimum content of *Pinus* pollen. As one can see from the diagram, it corresponds only to a part of the climatic optimum and provides grounds to correlate the interval with the upper interglacial beds of the Nizhninskii Rov (Kondratene and San'ko, 1985) and Krasnaya Dubrova (wells 13B and 55B, Makhnach *et al.*, 1982; Makhnach and Rylova, 1986) localities. This allows us to consider the beds in question as deposited during the Mogilev interglaciation.

The stratigraphically higher beds (depth interval of 6.1–14.5 m) display spore–pollen spectra sharply different in composition from the underlying interglacial flora. The abundance of arboreal pollen is decreased here (41–77%) in contrast to a higher content of herbaceous species (12–30%). Arboreal taxa from this level include *Betula* (*B. nana* L. and *B. humilis* Schrank representing up to 89% among them) and *Pinus* associated with *Juniperus* (2.5), *Larix* (1.5), and *Picea* (2). Pollen of *Artemisia* (83), *Ranunculus* (33), Cyperaceae (29), and Poaceae (19) is dominant among herbaceous taxa. Abundant spores of *Bryales* and *Sphagnum* coexist with less plentiful specimens of *Hypnum, Botrychium, Selaginella selaginoides* (L.) Lk., and Polypodiaceae. Accordingly, the climatic conditions of this time corresponded to environments of the present tundra and forest–tundra zones.

Paleocarpological data for 13 samples of flora-bearing rocks from the depth interval of 10.0–20.5 m revealed two floral assemblages different in age and characteristic features. We should note here that the boundary level between these assemblages conflicts somewhat with the boundary separating beds with contrasting spore–pollen spectra. For instance, the lower assemblage of carpogeneous flora totally corresponding to the interglacial vegetation is characteristic of the depth interval of 20.5–16.0 m, whereas palynospectra undoubtedly depicting this type of vegetation are detected in the interval of 19.0–19.6 m. This discrepancy is not of cardinal significance, but it is important for the detailed microstratigraphy.

Five samples from intervals other than that of 15.5–16.0 m, which yielded a limited amount of carpolites of low taxonomic diversity, contain uniform carpological assemblages. They exemplify the forest vegetation almost entirely consisting of conifers *Larix* and *Pinus* constantly accompanied by *Betula alba* L. A group of prime significance among abundant herbaceous plants is represented here by extinct species, such as *Potamogeton sarjanensis* Wieliczk., *Scirpus atroviroides* Dorof., *Carex paucifloroides* Wieliczk., *Brasenia borysthenica* Wieliczk., *Nymphaea cinerea* Wieliczk., and *Aldrovanda* cf. *borysthenica* Wieliczk. They are Pleistocene species proper, which originated in the Eopleistocene or at the beginning of the middle Pleistocene and whose combination is always typical of the optimum of the Belovezh'e interglaciation. These key species of the *Brasenia* assemblage coexisted with other thermophilic forms characteristic of the interglacial optimum, such as *Salvinia natans* (L.) All., *Sparganium microcarpum* (Neum.) Rank., *Potamogeton obtusifolius* Mert. et Koch, *P. compressus* L., *Butomus umbellatus* L., *Ceratophyllum demersum* L., and others. With the exception of *Betula humilis* Schrank, plants resistant to cold are missing in this flora, and the period of its development comprises at least part of the climatic optimum and post-optimum phases of the Belovezh'e interglaciation.

The upper floral assemblage of six samples from the depth interval of 15.5–10.0 m is considerably different in its dominant species and general composition. Conifers *Larix* and *Pinus* together with *Betula alba* L. are still dominant here, but they associate with *Carpinus* cf. *betuloides* Wieliczk. and *Corylus* sp. This seemingly insignificant difference implies an important change in the composition of forest communities reflecting a climatic optimum of another interglacial stage close in age to the previous one. Changes in assemblages of herbaceous plants were even more obvious. Their assemblages are very diverse and include about 25 new taxa absent in the lower flora. The most important among the latter are indicative representatives of the *Brasenia* fauna, such as *Dulichium arundinaceum* (L.) Britt., *Scirpus mucronatus* L., *S.* cf. *torreyi* Olney, *Potamogeton* ex gr. *acutifolius* Link, *P. panormitanoides* Dorof., *Lemna trisulca* L., *Cyperus glomeratus* L., *Ceratophyl-*

lum submersum L., *Caulinia* ex gr. *tenuissima* (A. Br. ex Magnus) Tzvel., *Elatine hydropiper* L., *Potamogeton nodosus* Poir., and some other forms. The abundance of these species suggests a warmer but less humid climate as compared to the previous period. This type of climate is characteristic of the Mogilev interglacial flora and has many features in common with the Belovezh'e flora.

An episode of cooling between these interglaciations is not very well featured by carpological data. The respective flora from the depth interval of 15.5–16.0 m is considerably less diverse as compared to carpolite assemblages in underlying and overlying beds. Almost all forest taxa, excluding cryophilic *Betula humilis* Schrank and *Potentilla* ex gr. *nivea* L., are absent here. Some usual and exotic species available in this interval were apparently introduced by inept drilling and coring regimes.

Consequently, the palynological and carpological data clearly show that this section of Well 3 near the village of Smolyarka consists of beds successively deposited during the Belovezh'e interglaciation, Nizhninskii glaciation, Mogilev interglaciation, and Berezina glaciation.

DISCUSSION AND CORRELATION

Belovezh'e Horizon

In all Belarussian localities of the Belovezh'e Horizon, the spore–pollen diagrams are of the same type and depict similar paleogeographic environments. In particular, these diagrams for three newly studied sections (Borki, Yatvez', and Smolyarka) are identical to diagrams characterizing the lower (Lyuban, Glazovo) optimum in the Nizhninskii Rov stratotype (Makhnach, 1971; Elovicheva, 1979; Voznyachuk, 1985; Kondratene and San'ko, 1985; Goretskii *et al.*, 1987) and in other sections studied in detail and located at the Krasnaya Dubrova of the Gomel region (Well 13B, Makhnach and Rylova, 1986) and at the Starobin and Kosteshi of the Minsk region (Makhnach, 1961, 1966; Logoiko and Elovicheva, 1975), or penetrated by wells 1474 and 1279 in the Bereza stratotype area (Velichkevich *et al.*, 1993).

In general, the sequence of vegetation phases in Belarus during the Belovezh'e interglaciation is as follows: (bl_1) birch–conifers (birch, larch, spruce, pine) and conifer–birch forests; (bl_2) birch–pine forests with accessory larch, spruce, alder, and broad-leaved trees and hazel undergrowth; (bl_3) mixed broad-leaved–coniferous (oak, elm, pine) forests with rare birch and alder trees; (bl_4) broad-leaved (oak, elm, linden, maple, ash) forests with pine and birch trees alternating with broad-leaved–coniferous forests, which had a thick hazel undergrowth and alder brushwood in humid depressions; (bl_5) broad-leaved–spruce–larch forests with abundant hazel and alder boscages; (bl_6) pine and pine–spruce forests with birch, alder, and some broad-leaved trees (oak, elm, linden); (bl_7) pine and pine–spruce forests with accessory birch trees; and (bl_8) coniferous–small-leaved (pine, spruce, larch, fir, birch) forests with rather abundant herbaceous vegetation.

Palynospectra of the Belovezh'e interglaciation differ from all other interglacial floras and display the following features: they show a considerable proportion of *Larix* and *Picea* pollen at the early interglacial phase (up to 14 and 12% respectively); emergence levels of broad-leaved taxa in them are asynchronous, and pollen of *Quercus* and *Ulmus* appears earlier than that of *Tilia* (up to 12%) and *Corylus* (up to 70%); pollen of *Quercus* (up to 61%) and *Ulmus* (up to 41%) is dominant among other broad-leaved taxa of the spectra at all stages of the climatic optimum; during the optimum, pollen of *Ulmus* is more abundant than in other interglacial assemblages, and it sometimes prevails even over the *Quercus* pollen, not to mention other broad-leaved taxa; pollen of *Alnus* (up to 33%) appears either concurrently with that of *Quercus* and *Ulmus* or somewhat later together with *Tilia* and *Corylus* pollen; pollen of dark coniferous *Abies* (1–4.5%, maximum 8%) and *Picea* (1–3.5%, maximum 22%) is regularly present in the terminal beds of the climatic optimum and coexists with pollen of broad-leaved taxa, hazel, and alder; pollen of *Carpinus* is either lacking or deficient.

Spore–pollen diagrams of the Belovezh'e interglaciation in Belarus are very similar to those of the Muchkap (Glazovo optimum) interglaciation in the Russian plain (Grichuk *et al.*, 1961; Krasnenkov and Pisareva, 1977; Biryukov and Valueva, 1981; Krasnenkov *et al.*, 1981; Maudina and Eremina, 1982; Kholmovoi *et al.*, 1984; Valueva *et al.*, 1985; Biryukov *et al.*, 1992). The similarity is expressed in the general taxonomic composition of spectra, and also in the sequence of pollen zones and in evolutionary phases of vegetation. Available disagreements are usually insignificant and depend on the different geographic position of the regions. For instance, the *Abies* pollen typical of the final stage of the climatic optimum in Belarus (especially in the west) is missing in the central areas of the Russian plain. In addition, pollen of *Corylus*, whose content can be as high as 70% in Belarus, is less abundant in Russia, and pollen of *Ulmus* sometimes prevailing over that of *Quercus* in the Belovezh'e interglacial optimum also shows a somewhat lower abundance in the last region.

The established palynological features of the Belovezh'e interglacial beds in Belarus are also typical of the reference section of the Ferdynandow Interglacial (phases 1–5) (Janczyk-Kopikowa *et al.*, 1981) and other coeval sequences exposed in the Lukow, Falecice, Bialobrzegow (profiles 71, 84, and 98), and "Buczyna pod brukiem" localities of Poland (Sobolewska, 1969; Lindner *et al.*, 1991; Janczyk-Kopikowa, 1991). However, the Ferdynandow interglacial beds, which contain, as in Belarus, abundant pollen of dark coniferous

Abies and *Picea*, also accommodate pollen admixtures of *Taxus, Celtis*, and *Ilex* that can be a result of geographic difference between the regions. Nevertheless, the palynological diagrams for interglacial deposits of Belarussian and Polish sections generally depict the same sequence and synchronism of floral evolutionary phases.

In addition, spore–pollen diagrams of the Belovezh'e Interglacial are obviously similar to the diagrams of the Artern interglacial beds in the Foighstedt locality of Germany (Erd, 1973, 1978). In comparison with Belarussian sections, these beds are richer in the *Taxus* pollen (up to 5%), but depleted in the *Corylus* specimens. Another unit correlative with the Belovezh'e interglacial strata is the Zhidini Interglacial of Latvia, referred to the early Pleistocene (Danilans *et al.*, 1964; Danilans, 1973; Kondratene *et al.*, 1985). Palynological characteristics of the Zhidini (depth interval of 146.6–152.7 m) and Belovezh'e units are identical.

Carpolites of the Belovezh'e time are known not only from sections described above, but also from Kosteshi, Nikolaevo, Obukhovo, and Motol' localities, and, in addition, they were recovered by wells 1382 (Signevichi), 5 (Rassvet), 41 (Chkalovo), 13B and 55B (Krasnaya Dubrova, the lower sapropelite beds). Main features of this paleoflora are as follows (Velichkevich, 1982; Yakubovskaya, 1986; Velichkevich *et al.*, 1993). First of all, the diverse group of arboreal and fruticose taxa of mixed coniferous–broad-leaved communities is very rich in conifers, mainly in *Larix decidua* Mill., which was abundant during the climatic optimum and marginal phases of the interglaciation. Another important element of these vegetal communities was pine, usually represented by the common European species *Pinus sylvestris* L. As a rule, carpolites of *Picea* are not abundant, especially in beds corresponding to the climatic optimum, but in addition to the widespread *Picea abies* (L.) Karst., they sometimes include the extinct *P. omoricoides* Web. genetically related to the present spruce *P. omorica* Panz. locally occurring in the mountains of Serbia. One more *Picea* species resembling the Siberian form *P. obovata* Ldb., but probably representing another individual taxon ex sect. *Picea*, was distinguished in the Nizhninskii Rov and Kosteshi sections as typical of the early interglacial phase. Carpolites of broad-leaved taxa, though not abundant even in the interval of the climatic optimum, represent diverse species of *Acer, Tilia, Fraxinus*, and *Quercus* genera existing at present.

Herbaceous flora of the Belovezh'e Interglacial includes over 200 taxa and is the most diverse among the interglacial floras of Belarus. In addition to dominant present-day species, it comprises many exotic forms, some of which are inherited from the Pliocene and Eopleistocene floras, and others represent the results of evolution of the early Pleistocene flora itself. The group of exotic herbaceous plants consists of the following species: *Sparganium* cf. *stenophyllum* Maxim., *Potamogeton sarjanensis* Wieliczk., *P. panormitanoides* Wieliczk., *Caulinia macrosperma* Wieliczk., *C. interglacialis* Wieliczk., *Stratiotes brevispermus* Wieliczk., *Scirpus atroviroides* Dorof., *Carex paucifloroides* Wieliczk., *Brasenia borysthenica* Wieliczk., *Euryale byelorussica* Wieliczk., *Nymphaea cinerea* Wieliczk., *Aldrovanda borysthenica* Wieliczk., and *Hypericum pleistocenicum* Wieliczk. The most characteristic species of the Belovezh'e flora are *Brasenia borysthenica* Wieliczk. s.s., *Caulinia macrosperma* Wieliczk., *Euryale byelorussica* Wieliczk., *Potamogeton sarjanensis* Wieliczk., and *Aldrovanda borysthenica* Wieliczk., whose carpolites are either missing in deposits of another age, or known as single specimens from neighboring interglacial beds, where they display atypical morphological features. Some of the extinct species, for instance, *Azolla interglacialis* Nikit. usual in the younger Aleksandriya flora, or *Caulinia interglacialis* Wieliczk. characteristic of other middle Pleistocene floras, are unusual elements among Belovezh'e carpolites. *Stratiotes brevispermus* Wieliczk. and *Euryale byelorussica* Wieliczk. are also scarce among them. Having an apparent interglacial affinity and diverse *Brasenia* assemblage, the Belovezh'e flora differs from older floras of the Korchevo type. As compared to later Mogilev and, especially, Aleksandriya floras, it shows a distinctive spectrum of exotic forms and depicts another general type of vegetation.

In central regions of the Russian plain, the closest counterparts of the Belovezh'e carpolites are those from the Glazovo optimum of the Muchkap Interglacial, as follows from data obtained by the uniform analytical method in the Dronovka, Ignatkovo–Smolensk, Shapkovo–Tver, Glazovo–Kaluga, and Akulovo–Moscow areas (Velichkevich, 1982), and also in the Roslavl' stratotype region (Biryukov *et al.*, 1992), the Pol'noe Lapino lacustrine deposits (Valueva *et al.*, 1985), and other less representative localities.

The Ferdynandow Interglacial of Poland is characterized by few carpological data. Despite this, the direct comparison of carpolites from Ferdynandow and Belovezh'e beds shows that they include many identical exotic taxa.

In addition to sections described above, the diatom flora of the Belovezh'e interglaciation in Belarus was studied in wells 13B and 55B of the Krasnaya Dubrova locality (lower sapropelite beds), in Well 41 near the village of Rassvet, and in Well 5 near the village of Chkalovo (Khursevich and Loginova, 1986). This flora, consisting of 275 specific and intraspecific taxa, demonstrates the following features: (a) a high abundance of extinct Pliocene–Pleistocene forms, such as *Cyclotella radiosa* var. *pliocaenica* (Krasske) Häkansson (up to 30%) and *C. radiosa* var. *lichvinensis* (Jousé) Log. (up to 25%); (b) a significant proportion of *Cyclotella reczickiae* Churs. et Log. (up to 11%), *Stephanodiscus determinatus* Churs. (up to 16%), *S. styliferum* Churs. (up to 2%), *S. raripunctatus* Churs. et Log. (up to 17%),

Correlated stratigraphic schemes of the middle Pleistocene in Belarus and other countries

Belarus (Velichkevich *et al.*, 1996)			Central Russia (Breslav *et al.*, 1992)		Poland (Mojski, 1993)	Holland (Zagwijn, 1985)	
	Dnjeperian		Moskovian		Middle Polish (Odra);	Saalian	
Mesopleistocene	Aleksandriya		Likhvinian		Mazowieckian	Holsteinian	
	Berezina		Michurin	Okaian	Vilga (San II)	Elsterian	
	Mogilev			Muchkap	Ferdynandow	Cromerian	Interglacial IV
	Nizhninskii						
	Belovezh'e						
	Minsk	Yasel'da		Don	South Polish		Glacial C
		Korchevo	South Voronezh	Il'inka	Pshaenysh		Interglacial III
		Narev		Pokrovka	Narev		Glacial B
							Interglacial II
Eopleistocene				Petropavlovsk			Glacial A
							Interglacial I
			Eopleistocene		Eopleistocene	Eopleistocene	

Navicula variabilis Churs. et Log. (up to 3.4%), and *N. jentzschii* f. kuptzoviae Churs. (up to 4.1%), which are the index species of the Belovezh'e Interglacial; (c) a high content of *Cyclotella reczickiae* var. *diversa* Log. (up to 46%) and *Stephanodiscus peculiaris* Churs. (up to 22%) first discovered in the Belovezh'e beds and survived in the Likhvinian and Mikulinian floras; (d) an intense development of *Stephanodiscus niagarae* var. *insuetus* Churs. et Log. (up to 35%), which ceased to live before the end of the middle Pleistocene, and an abundance of forms transitional between *S. niagarae* var. *insuetus* Churs. et Log. and *S. rotula* (Kütz.) Hendey.

These features of the Belovezh'e diatom flora demonstrate its similarity with diatom assemblages from many localities in central Russia, such as Pol'noe Lapino and Tambov in the Don River basin, Bibirevo in the Volga River basin between Yaroslavl and Kostroma, Podrudnyanskii in the upper courses of the Dnieper River, and Balashikha in the head area of the Oka River (Antsiferova, 1987, 1991). The diatom species and subspecies listed above and important for stratigraphy and correlation are known from all mentioned localities. A certain difference between individual sections in the abundance of some of these indicative and dominant taxa is related to the facial diversity of the localities and to the various character of respective paleobasins.

The Belovezh'e diatom flora from Belarus is to a certain degree compatible with the diatom assemblage from the Zhidini section (depth interval of 146.6–152.7 m) located in southern Latvia (Khursevich, 1984; Kondratene *et al.*, 1985). Both floras include the extinct Pliocene relics of the genus *Cyclotella* (Kütz.) Bréb. including *Cyclotella reczickiae* Churs. et Log., one of the index species of the Belovezh'e Interglacial. At the same time, each flora is peculiar, because the Zhidini section accommodates the Miocene relic *Cyclostephanos costatus* now dwelling in water basins of eastern Siberia, whereas the Belovezh'e flora is distinct due to some representatives of the genus *Stephanodiscus* Ehr., indicative of the stratigraphic interval in question.

Finally, the Belovezh'e diatom flora from Belarus is very similar to the corresponding assemblage of these algae from the Ferdynandow section of Poland (depth interval of 43.7–51.7 m, Khursevich *et al.*, 1990). The identical age of both is evident from the high percentage of common forms (87.9%), including dominant and extinct taxa such as *Cyclotella radiosa* var. *pliocaenica* (Krasske) Häkansson, *C. radiosa* var. *Lichvinensis* (Jousé) Log., *C. reczickiae* Churs. et Log. var. *reczickiae* et var. *diversa* Log., *Stephanodiscus niagarae* var. *insuetus* Churs. et Log., *S. peculiaris* Churs., and *Navicula variabilis* Churs. et Log. Furthermore, the *Cyclotella* species (including *C.* cf. *reczickiae* Churs. et Log.) are abundant in the Belkhatov section, whereas the *Stephanodiscus rotula* (Kütz.) Hendey/*S. niagarae* Ehr. assemblage is known from the Podleduw section, and respective beds in both localities are referred to the Ferdynandow Interglacial (Marciniak, 1990). Thus, the diatom floras provide sufficient grounds to correlate the Belovezh'e interglaciation with the Muchkap interglacial stage of central Russia, Zhidini Interglacial of Latvia, and Ferdynandow Interglacial of Poland (see table).

Nizhninskii Horizon

Periglacial environments of the post-Belovezh'e time resembling the climate of the present-day tundra

zone are detectable from spore–pollen diagrams characterizing many Belarussian sections. Using the data of Makhnach for the Nizhninskii Rov holostratotype, Voznyachuk (1985) distinguished here two horizons deposited during two cooling phases and an interstadial separating them. Kondratene and San'ko (1985) arrived at the same conclusion and even argued for a rather severe subarctic climate during the stadial phases. The very detailed palynological data on subdivisions of the Nizhninskii interval were obtained by Rylova from Well 1474 near the village of Golitsy of the Bereza stratotype area (see in Velichkevich *et al.*, 1993). Both stadial and interstadial horizons of this section received their own names and palynological interpretation. While recently analyzing data of Tsapenko and Makhnach (1966) on Well 21 near the village of Ugly, the Berezina River Basin between Bobruisk and Parichi, we even identified two interstadials and three stadials above the Belovezh'e beds. Periglacial environments of the Nizhninskii time are also clearly detectable on the basis of spore–pollen (Makhnach and Rylova, 1986) and diatom (Khursevich and Loginova, 1986) analyses of the Krasnaya Dubrova section (Well 55B) in the Rechitsa region.

Deposits of the Nizhninskii glaciation can be well correlated with coeval strata in neighboring countries, in particular with a horizon of "intermediate cooling" present in some sections of the Roslavl' stratotype region of Russia and bearing certain elements of the Tiraspol' fauna (Biryukov *et al.*, 1992), and also with beds of the Zhidini section in Latvia, which yielded "cryophilic" spore–pollen and diatom assemblages (Kondratene *et al.*, 1985). The interstadial horizons are also distinguished in these sections. A period of considerable cooling separating two interstadials is reflected as well in spore–pollen diagrams of the Ferdynandow type characterizing the Bialobrzegow section (Janczyk-Kopikowa, 1991).

The complex of paleobotanical data shows that deposits of the Nizhninskii Horizon enclose floral remains of forest-free landscapes resembling tundra even in southern Belarus. Accordingly, the climatic cooling of that time was rather significant, although the morainal beds are missing in all aforementioned sections. We expect, however, that real morains may still be discovered, especially in the northwestern areas of the East European platform, when deposits of the Nizhninskii type will be better studied.

Mogilev Horizon

The Mogilev interglacial deposits of southwestern Belarus are well correlative with coeval beds in other areas of the country, although some of the sections are inadequately studied. For instance, we have no data on diatoms from the Nizhninskii Rov stratotype of this interglaciation, whereas they are guide fossils in the Krasnaya Dubrova section, and stratigraphy of the Pushkari section in the Vitebsk region is completely based on carpolites.

Among many spore–pollen diagrams obtained by Makhnach, Elovicheva, Kondratene, and Rylova, who studied materials from the Nizhninskii Rov locality, one from the stripped Exposure 2 best depicts the evolutionary patterns of vegetation during the Mogilev interglaciation (Kondratene and San'ko, 1985). Four zones of dominant pollen taxa are detected here in the interglacial beds and correspond to the following forest groupings: (XII) birch–larch–pine; (XIII) oak–elm–linden; (XIV) hornbeam–oak–elm–linden–spruce–pine; and (XV) birch–pine–larch. We should note that diagrams for different wells and exposures are dissimilar with respect to general spectra, first occurrence levels, and peak abundances of arboreal pollen. For instance, some of them show that broad-leaved *Alnus* and *Corylus* are taxa that appeared before the others, while in another case the earliest taxon can be represented either by *Quercus*, or by *Carpinus*. At the same time, the peak abundance in the spectra may belong to *Quercus* in one locality, and then to *Carpinus* in another site. All these features suggest that no section of the Mogilev deposits in the Nizhninskii Rov area recorded the entire climatic optimum, not to mention the whole interval of this interglaciation.

In the Krasnaya Dubrova locality (Well 13B), the Mogilev beds yielded one spore–pollen assemblage divided into three subassemblages (Makhnach *et al.*, 1982; Makhnach and Rylova, 1986). At the beginning of this interglaciation, the pine–birch forests gave way to pine–spruce–birch vegetation with accessory broad-leaved taxa and hazel boscage (subassemblage 5a). The next optimum phase (subassemblage 5b) produced abundant pollen of broad-leaved trees, such as *Quercus* (18), *Tilia* (4.5), *Ulmus* (9), *Fraxinus* (2), *Carpinus* (1.5), *Alnus* (40), and *Corylus* (22), and corresponds to the time of coniferous–broad-leaved vegetation with alder brushwood. Subassemblage 5c is compatible with the phase of pine and pine–spruce forests with rare broad-leaved trees. Deposits of the climatic optimum (subassemblage 5b) in Well 55B, located 400 m away from the previous site, display the following pollen spectrum: *Carpinus* (31), *Quercus* (9), *Ulmus* (4), *Tilia* (3), *Alnus* (18), and *Corylus* (6). Three taxa, *Quercus, Tilia,* and *Ulmus*, appeared in this section before *Carpinus, Alnus*, and *Corylus*.

Palynospectra of the Mogilev interglaciation are well correlative with spore–pollen diagrams of Well 420, Konakhovka locality of central Russia (Biryukov *et al.*, 1992), and with coeval spectra of the Ferdynandow (Janczyk-Kopikowa, 1975) and Bialobrzegow (profiles 71, 84, and 98, Janczyk-Kopikowa, 1991) sections of Poland.

Two horizons, corresponding to the Belovezh'e and Mogilev interglaciations and separated by interstadial beds, are also distinguished in the Zhidini section of southern Latvia (Kondratene *et al.*, 1985). In the upper

interglacial horizon, the dominant forms are the conifers *Pinus* (25–40%) and *Picea* (10–39%). Broad-leaved taxa (15–32% in total) are represented by the dominant *Carpinus* (up to 25%) associated with *Corylus* (2–7%) and *Alnus* (10–12, maximum 29%). Exotic forms available here include *Picea* sect. *Omorica*, *Pinus* sect. *Strobus* sect. *Strobusae*, *Carpinus* sp., *Celtis, Ligustrum, Vitis, Osmunda*, and *Salvinia*, many of which are also typical of coeval sections in Belarus.

As reported (Velichkevich and San'ko, 1993), carpolites of the Mogilev interglaciation have their analogues in the flora of the Pushkari section in the Vitebsk region; however, some of us do not agree with this inference. Flora of this section is not very representative (48 taxa) and includes only few exotic species. Nevertheless, *Carpinus betuloides* Wieliczk., characteristic of this flora, *Nymphaea cinerea* Wieliczk., *Ranunculus sceleratoides* Nikit., and associated exotic forms *Lemna* sp. and *Rubus* cf. *occidentalis* L. demonstrate the ancient aspect of the assemblage.

The Mogilev flora is correlative with carpological assemblages from the Konakhovka beds of central Russia; however, its correlation with deposits of the Smolenskii Brod locality (Vaznyachuk *et al.*, 1979) is more problematic. Carpological characteristics of these beds allow them to be correlated with the upper flora of the Smolyarka section and thereby with other Mogilev floras, yet palynospectra of the beds are quite peculiar. Interglacial deposits of this locality are well exposed and perfectly studied in many aspects in contrast to fragmentary biostratigraphic units recovered by drilling, and this brings forth problems in correlation analysis. The same is true of the Nizhninskii Rov locality, where palynospectra show a considerable diversity, as already noted. We believe that all these aspects represent subjects for special studies in the future.

The Mogilev Horizon of the Nizhninskii Rov locality bears abundant carpolites of *Carpinus* cf. *betuloides* Wieliczk., *Hypericum pleistocenicum* Wieliczk., and *Brasenia borysthenica* Wieliczk. s.s. associated with less representative *Aldrovanda borysthenica* Wieliczk., *Nymphaea cinerea* Wieliczk., and some exotic forms. This assemblage of predominantly helobious coenoses includes only few taxa of true aquatic type (*Azolla, Caulinia, Potamogeton*, and others), many of which correspond to ancient extinct species. Nonetheless, correlation between the Nizhninskii and other floras of the Mogilev type seems to be quite correct on the basis of characteristic forms and the evolutionary status of many usual species.

The diatom flora of the Mogilev interglaciation from Well 13B near the village of Krasnaya Dubrova (depth interval of 26.2–28.0 m) includes a set of dominant species different from that of the Yatvez' section. Leading genera in this flora are *Aulacoseira* and *Stephanodiscus*. Main species of the former are *Aulacoseira granulata* (Ehr.) Sim. (30–50, maximum 74%) and *A. italica* (Ehr.) Sim. (9–50%). The dominant form of *Stephanodiscus* genus is represented by the extinct *S. niagarae* var. *insuetus* Churs. et Log. (up to 17%) constantly associated with less abundant *S. rotula* (Kütz.) Hendey (up to 3.4%) and *S. parvus* Stoermer et Häkansson (0.5–1.5%). However, *S. styliferum* Churs. typical of the older Belovezh'e interglaciation is missing here. The content of *Cyclotella* species is below 5–9%, and they include only scanty specimens of *C. radiosa* var. *pliocaenica* (Krasske) Häkansson, whereas *C. reczickiae* Churs. et Log. is missing. Other planktonic species of diatoms are represented in this flora by *Asterionella formosa* Hassal (4–5%) and *Fragilaria crotonensis* Kitt. (2–7%).

Away from Belarus, the diatom flora of the Mogilev interglaciation is recorded in the Zhidini section of Latvia within the depth interval of 131.3–134.5 m. Its dominant forms belong to the planktonic genus *Stephanodiscus* Ehr., first of all to the extinct species *S. niagarae* var. *insuetus* Churs. et Log. (up to 58%), and to less abundant *S. minutulus* (Kütz.) Cleve et Möller (10–35%) and *S. parvus* Stoermer et Häkansson (up to 35%). *Aulacoseira* species represent 13–42% of the assemblages, and *Cyclotella* forms are not abundant.

So far, the diatom flora of the Mogilev interglaciation is poorly studied. To make progress in this direction, it is necessary to explore other localities of these fossils and to study them in detail.

CONCLUSION

Palynological, carpological, and diatom analyses of new sections in southwestern Belarus (Well 2G near the village of Borki, Well 6 near the village of Yatvez', and Well 3 near the village of Smolyarka) provided data for a deeper insight into the paleobotanical characteristics of the Belovezh'e, Nizhninskii, and Mogilev horizons of the regional Pleistocene sections. The spore–pollen diagrams and new data on carpolites and diatom floras allow us to substantiate the pre-Aleksandriya, or more precisely the pre-Berezina age of these horizons. All the paleobotanical data led us to the conclusion that the Belovezh'e interglacial beds and deposits of the "lower optimum" of the Shklov interglaciation are coeval.

The interval of the Belovezh'e, Nizhninskii, and Mogilev horizons is correlated with the Muchkap (Roslavl') Horizon of central Russia, Zhidini Horizon of Latvia, and Ferdynandow Interglacial of Poland. We also inferred that the Berezina Horizon overlying them is correlative with the Okaian glaciohorizon of central Russia, Dainava Horizon of Latvia, and Vilga Horizon of Poland. In the new stratigraphic scheme of the Quaternary in Belarus (Velichkevich *et al.*, 1995), all the listed horizons are referred to the middle Pleistocene. The lower boundary of the middle Pleistocene is placed at the base of the oldest glacial beds of the Narev Horizon, i.e., close to the Brunhes–Matuyama reversal. Its upper boundary marks the base of glacial deposits of the Dnjeperian Horizon.

ACKNOWLEDGMENTS

This work was supported by the International Science Foundation (grant no. MWL 300), and by the Government of Belarus.

Reviewer M.N. Alekseev

REFERENCES

Antsiferova, G.A., Diatom Flora from the Lower Pleistocene (Muchkap) Deposits, *Al'gologiya,* 1981, vol. 1, no. 1, pp. 104–108.

Antsiferova, G.A., The Early Pleistocene (Muchkap) Diatom Flora from Central Regions of the East European Plain: Its Stratigraphic and Paleogeographic Significance, *Cand. Sci. (Geol.–Mineral.) Dissertation,* Tallinn: Inst. of Geology, Estonian Acad. Sci., 1987.

Biryukov, I.P. and Valueva, M.N., A Section of the Roslavl' Interglacial Deposits near the Village of Dronovka, the Safonovo District of the Smolensk Region, in *Kompleksnoe izuchenie opornykh razrezov nizhnego i srednego pleistotsena evropeiskoi chasti SSSR* (Multipurpose Study of Reference Sections of the Lower and Middle Pleistocene in the European Part of the USSR), Moscow: Geol. Fond RSFSR, 1981, pp. 39–50.

Biryukov, I.P., Agadzhanyan, A.K., Valueva, M.N., *et al.,* Quaternary Deposits in the Roslavl' Stratotype Region, in *Stratigrafiya i paleogeografiya chetvertichnogo perioda Vostochnoi Evropy* (Quaternary Stratigraphy and Paleogeography of the Eastern Europe), Moscow: Inst. Geografii Ross. Akad. Nauk, 1992, pp. 152–180.

Breslav, S.L., Valueva, M.N., Velichko, A.A., *et al.,* Stratigraphic Scheme of Quaternary Deposits for Central Regions of Eastern Europe, in *Stratigrafiya i paleogeografiya chetvertichnogo perioda Vostochnoi Evropy* (Quaternary Stratigraphy and Paleogeography of Eastern Europe), Moscow: Inst. Geografii Ross. Akad. Nauk, 1992, pp. 8–36.

Danilans, I.Ya., *Chetvertichnye otlozheniya Latvii* (Quaternary Deposits in Latvia), Riga: Zinatne, 1973.

Danilans, I.Ya., Dzilna, V.Ya., and Steple, V.Ya., Zhidini Section, in *Voprosy chetvertichnoi geologii* (Problems of Quaternary Geology), Riga: Zinatne, 1964, vol. 3, pp. 63–140.

Elovicheva, Ya.K., *Shklovskie (roslavl'skie) mezhlednikovye otlozheniya Belorussii i smezhnykh territorii* (Interglacial Shklov (Roslavl') Deposits in Belarus and Adjacent Regions), Minsk: Nauka i Tekhnika, 1979.

Erd, K., Pollenanalytische Gliederung des Pleistozens der Deutschen Demokratischen Republik, *Z. Geol. Wiss. Berlin,* 1973, vol. 1, no. 9, pp. 1087–1100.

Erd, K., Pollenstratigraphie im Gebiet der skandinavischen Vereisungen, *Schriff. geol. Wiss. Berlin,* 1978, no. 9, pp. 99–119.

Goretskii, G.I., *Osobennosti paleopotamologii lednikovykh otlozhenii (na primere Belorusskogo Poneman'ya)* (Peculiarities of Paleopotamology of Glacial Deposits with the Neman Region of Belarus as an Example), Minsk: Nauka i Tekhnika, 1980.

Goretskii, G.I., Gurskii, B.N., Elovicheva, Ya.K., *et al., Nizhninskii Rov (stratotipicheskii razrez shklovskogo mezhlednikov'ya Belorussii)* (Nizhninskii Rov: The Stratotype Section of the Shklov Interglaciation in Belarus), Minsk: Nauka i Tekhnika, 1987.

Grichuk, V.P., Monoszon, M.Kh, and Shik, S.M., Deposits of the Odintsovo (Dnjeperian–Moskovian) Interglacial Stage near the Village of Glazovo, in *Paleogeografiya chetvertichnogo perioda SSSR* (Quaternary Paleogeography of the USSR), Moscow: Mosk. Gos. Univ., 1961, pp. 69–74.

Gurskii, B.N., *Nizhnii i srednii antropogen Belorussii* (The Lower and Middle Anthropogene in Belarus), Minsk: Nauka i Tekhnika, 1974.

Janczyk-Kopikowa, Z., Flora interglacjalu mazowieckiego w Ferdynandowe, *Biul. Inst. Geol.* (Warsaw), 1975, no. 290, pp. 5–50.

Janczyk-Kopikowa, Z., The Ferdynandow Interglacial in Poland, *Kwart. Geol.,* 1991, vol. 35, no, 1, pp. 71–80.

Janczyk-Kopikowa, Z., Mojski, J.E., and Rzechowski, J., Position of the Ferdynandow Interglacial, Middle Poland, in the Quaternary Stratigraphy of the European Plain, *Biul. Inst. Geol.* (Warsaw), 1981, no. 335, pp. 65–79.

Kholmovoi, G.V., Valueva, M.N., Antsiferova, G.A., *et al.,* Pol'noe Lapino, in *Opornye razrezy nizhnego pleistotsena basseina Verkhnego Dona* (Reference Sections of the Lower Pleistocene in the Don River Head), Voronezh: Voronezh. Univ., 1984, pp. 116–138.

Khursevich, G.K., Stratigraphy of Pleistocene Deposits in the Baltic Region as Indicated by Diatom Analysis, in *Paleogeografiya chetvertichnogo perioda Pribaltiki i sopredel'nykh raionov* (Quaternary Paleogeography of the Baltic and Adjacent Regions), Vilnius: Akad. Nauk LitSSR, 1984, pp. 122–129.

Khursevich, G.K. and Loginova, L.P., The Age and Paleogeographic Conditions of Accumulation of Ancient Lacustrine Deposits in the Dnieper Region near Rechitsa as Indicated by Data on Diatoms, in *Pleistotsen Rechitskogo Pridneprov'ya Belorussii* (Pleistocene of the Dnieper Region near Rechitsa in Belarus), Minsk: Nauka i Tekhnika, 1986, pp. 76–142.

Khursevich, G.K., Prszibylowska-Lange, V., and Loginova, L.P., Age Compatibility of Pleistocene Diatom Floras from the Krasnaya Dubrova (BSSR) and Ferdynandow (Poland) Sections, *Dokl. Akad. Nauk BSSR,* 1990, vol. 34, no. 2, pp. 179–183.

Khursevich, G.K., Rylova, T.B., and Litvinyuk, G.I., Abstracts of Papers, *Tezisy Vserossiiskogo soveshchaniya po izucheniyu chetvertichnogo perioda* (All-Russia Conf. on Study of the Quaternary System), Moscow: Geol. Inst. Ross. Akad. Nauk, 1994, p. 251.

Kondratene, O.P. and San'ko, A.F., Bedding and Palynology of Interglacial Deposits in the Nizhninskii Rov, in *Problemy Pleistotsena* (Problems of the Pleistocene), Minsk: Nauka i Tekhnika, 1985, pp. 101–124.

Kondratene, O.P., Khursevich, G.K., and Loginova, L.P., Biostratigraphic Age Substantiation of the Lacustrine Deposits Exposed in the Zhidini Section, in *Problemy Pleistotsena* (Problems of the Pleistocene), Minsk: Nauka i Tekhnika, 1985, pp. 86–101.

Krasnenkov, R.V. and Pisareva, V.V., A New Section of the Roslavl' Interglacial at the Nizhnedolgovskii Farm, the Volgograd Region, *Dokl. Akad. Nauk SSSR,* 1977, vol. 232, no. 5, pp. 1154–1157.

Krasnenkov, R.V., Valueva, M.N., Shuleshkina, E.A., and Maiorova, Yu.I., Pol'noe Lapino, the Reference Section of the Quaternary (Cromerian) Post-Morainal Deposits in the Don River Basin, in *Kompleksnoe izuchenie opornykh*

razrezov nizhnego i srednego pleistotsena evropeiskoi chasti SSSR (Multipurpose Study of Reference Sections of the Lower and Middle Pleistocene in the European Part of the USSR), Moscow: Geol. Fond RSFSR, 1981, pp. 11–23.

Lindner, L., Marciniak, B., and Ziembinska-Tworzydlo, M., Osady interglacjalne w Falecicach vraz ich znaczenie dla stratigrafii plejstocenu w dorzeczu dolnej Pilicy (Polska srodkowa), *Ann. Soc. Geol. Polon.*, 1991, vol. 61, pp. 231–256.

Logoiko, A.T. and Elovicheva, Ya.K., A Section of Interglacial Deposits near the Village of Kosteshi, the Lyuban' District of the Minsk Region, in *Stratigrafiya i paleogeografiya antropogena* (Stratigraphy and Paleogeography of the Anthropogene), Minsk: Nauka i Tekhnika, 1975, pp. 79–89.

Makhnach, N.A., Stratigraphic Significance of the Early to Incipient Middle Anthropogene Vegetation in Belarus, in *Materialy po antropogenu Belorussii* (Materials on the Anthropogene in Belarus), Minsk: Akad. Nauk BSSR, 1961, pp. 116–158.

Makhnach, N.A., A Section of the Roslavl' (Odintsovo, Dnjeperian–Moskovian) Interglacial Deposits near the Starobin Settlement, in *Stratigrafiya, litologiya i poleznye iskopaemye BSSR* (Stratigraphy, Lithology, and Mineral Deposits of the BSSR), Minsk: Nauka i Tekhnika, 1966, pp. 8–12.

Makhnach, N.A., *Etapy razvitiya rastitel'nosti Belorussii v antropogene* (Evolutionary Stages of Vegetation in Belarus during the Anthropogene), Minsk: Nauka i Tekhnika, 1971.

Makhnach, N.A. and Rylova, T.B., Stratigraphic Subdivision of the Pleistocene Lacustrine Deposits in the Dnieper Region near Rechitsa, in *Pleistotsen Rechitskogo Pridneprov'ya Belorussii* (Pleistocene of the Dnieper Region near Rechitsa in Belarus), Minsk: Nauka i Tekhnika, 1986, pp. 56–75.

Makhnach, N.A., Khursevich, G.K., Loginova, L.P., and Bogomolova, L.N., New Paleobotanical Investigations of the Pleistocene Lacustrine Deposits in the Krasnaya Dubrova Section, in *Neogenovye otlozheniya Belorussii* (Neogene Deposits in Belarus), Minsk: Nauka i Tekhnika, 1982, pp. 37–53.

Marciniak, B., Dominant Diatoms in the Interglacial Lake Sediments of the Middle Pleistocene in Central and Eastern Poland, *Hydrobiologia*, 1990, vol. 214, pp. 253–258.

Maudina, M.I. and Eremina, A.V., New Data on the Lacustrine Deposits in the Tambovskii Gorge, in *Pogranichnye gorizonty neogena i antropogena territorii KMA i Verkhnego Dona* (Neogene–Anthropogene Boundary Horizons in the Kursk Magnetic Anomaly Area and Don River Head), Voronezh: Voronezhskii Univ., 1982, pp. 80–89.

Mojski, J.E., *Europa w plejstocenie*, Warsaw: Polska Agencja Ekologiczna, 1993.

Rylova, T.B. and Khursevich, G.K., Plants and Diatom Flora from a New Section of the Belovezh'e Interglacial Deposits in Byelorussia, *Dokl. Akad. Nauk. BSSR*, 1989, vol. 33, no. 11, pp. 1025–1027.

Rylova, T.B., Palynological Characteristics and Correlation of Two Interglacial Horizons in the Smolyarka Section of the Brest Region, *Dokl. Akad. Nauk. BSSR*, 1985, vol. 29, no. 3, pp. 263–266.

Sobolewska, M., Osady interglacjalne w Zukowie na Podlasiu w swiete analizy pylkowej, *Biul. Inst. Geol.*, 1969, no. 220, pp. 105–112.

Tsapenko, M.M. and Makhnach, N.A., Stratigraphy of the Anthropogene Sequence in the Berezina River Valley, in *Paleontologiya i stratigrafiya BSSR* (Paleontology and Stratigraphy of the BSSR), Minsk: Nauka i Tekhnika, 1966, pp. 298–327.

Valueva, M.N., Dorofeev, P.I., Iosifova, Yu.I., *et al.*, Interglacial Lake of the Pol'noe Lapino: A Unique Object of the Lower Pleistocene in the Don Region, *Byull. Kom. Izuch. Chetvertichn. Perioda, Acad. Nauk SSSR*, 1985, no. 54, pp. 40–65.

Vaznyachuk, L.M., Makhnach, N.A., San'ko, A.F., *et al.*, Interglacial Deposits of the Smolenskii Brod Locality at the Zapadnaya Dvina River, the Velizh District of the Smolensk Region, in *Novae u geologii antrapagenu Belarusi* (News of Anthropogene Geology in Belarus), Minsk: Nauka i Tekhnika, 1979, pp. 64–79.

Velichkevich, F.Yu., *Pleistotsenovye flory lednikovykh oblastei Vostochno-Evropeiskoi ravniny* (Pleistocene Floras from Glaciation Areas of the East European Plain), Minsk: Nauka i Tekhnika, 1982.

Velichkevich, F.Yu., New Discovery of the Shklov Type Flora in Byelorussia, *Dokl. Akad. Nauk BSSR*, 1985, vol. 29, no. 4, pp. 363–366.

Velichkevich, F.Yu. and Rylova, T.B., New Discovery of the Early Pleistocene Flora in Southeastern Byelorussia, *Dokl. Akad. Nauk BSSR*, 1988, vol. 32, no. 11, pp. 1014–1017.

Velichkevich, F.Yu. and San'ko, A.F., Vitebsk Interglaciation in Belarus, *Stratigr. Geol. Korrelatsiya*, 1993, vol. 1, no. 3, pp. 120–124.

Velichkevich, F.Yu., Rylova, T.B., San'ko, A.F., and Fedenya, V.M., *Berezovskii stratoraion pleistotsena Belorussii* (The Bereza Stratotype Area of the Pleistocene in Belarus) Minsk: Nauka i Tekhnika, 1993.

Velichkevich, F.Yu., San'ko, A.F., Rylova, T.B., *et al.*, Stratigraphic Scheme of the Quaternary (Anthropogene) Deposits in Belarus, *Stratigr. Geol. Korrelatsiya*, 1996, vol. 4, no. 6, pp. 75–81.

Voznyachuk, L.N., Deposits of the Last Interglaciation in Byelorussia, in *Materialy po antropogenu Belorussii* (Materials on the Anthropogene in Belarus), Minsk: Akad. Nauk BSSR, 1961, pp. 159–217.

Voznyachuk, L.N., Main Stratigraphic Subdivisions of the Quaternary Deposits, in *Materialy po stratigrafii Belorussii* (Materials on the Stratigraphy of Belarus), Minsk: Nauka i Tekhnika, 1981, pp. 137–151.

Voznyachuk, L.N., Problems of the Glaciopleistocene of the East European Plain, in *Problemy pleistotsena* (Problems of the Pleistocene), Minsk: Nauka i Tekhnika, 1985, pp. 8–55.

Voznyachuk, L.N., Gripinskii, N.M., and Puzanov, L.T., Quaternary System, in *Geologiya SSSR* (Geology of the USSR), Moscow: Nedra, 1971, vol. 3, pp. 231–291.

Yakubovskaya, T.V., The Structure and Age of the Vedrichskie Seshchi Locality, in *Pleistotsen Rechitskogo Pridneprov'ya Belorussii* (Pleistocene of the Dnieper Region near Rechitsa in Belarus), Minsk: Nauka i Tekhnika, 1986, pp. 142–158.

Yakubovskaya, T.V., Khursevich, G.K., and Rylova, T.B., New Data on the Stratotype of the Belovezh'e Interglacial, *Dokl. Akad. Nauk. BSSR*, 1991, vol. 35, no. 3, pp. 262–265.

Zagwijn, W.H., An Outline of the Quaternary Stratigraphy of the Netherlands, *Geol. Mynbouw*, 1985, vol. 64, pp. 17–24.

Stratigraphy and Geological Correlation, Vol. 5, No. 4, 1997, pp. 391–400. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 4, 1997, pp. 85–94.
Original Russian Text Copyright © 1997 by Mikhailov.
English Translation Copyright © 1997 by MAIK Nauka/Interperiodica Publishing (Russia).

Correlation of Tectono-Stratigraphic Complexes of the Southeastern Sikhote Alin

V. A. Mikhailov

Far East Geological Institute, Far East Division, Russian Academy of Sciences, Akademgorodok, Vladivostok, 690022 Russia

Received March 20, 1995

Abstract—Based on the analysis of sections of the southeastern Sikhote Alin (Primor'e), it is inferred that the subdivision and mapping of chaotic olistostrome complexes by traditional stratigraphic methods is impossible. Tectono-stratigraphic complexes, which include proto-, paleo-, meso- and neoautochthon, suballochthon, and neoallochthon, along with allochthons I–VIII, are suggested to be used as basic units. The complexes of the region were compared and correlated, and regular series and associations representing a complicated history of stratified accretionary prisms of the northwestern Pacific framing were distinguished.

Key words: *Sikhote Alin, tectono-stratigraphic complex, Jurassic, Cretaceous, olistostromes*

INTRODUCTION

Traditional views on the geological structure of Primor'e were based on the idea of the autochthonous position (with regard to folding) of stratigraphic units in the structure of the Sikhote Alin folded system, which was subdivided into structural–lithologic zones (SLZ) with a normal, as was held, stratigraphic bed succession and a specific history of their formation (Belyaevskii *et al.*, 1955; *Geologiya SSSR...*, 1969; Vasil'kovskii, 1984; Oleinik, 1983; Nazarenko and Bazhanov, 1987). In particular, the Pribrezhnaya, Eastern, and Central SLZs were distinguished with the Partizansk–Okrainka, Ariadnoe, Samarka and Dal'nee subzones in the last (Fig. 1). However, new data, obtained recently, made it necessary to revise traditional views not only on the stratigraphy, but also on the Late Paleozoic–Early-Middle Mesozoic structure and history of Sikhote Alin. A wide distribution of Jurassic and Early Cretaceous olistostromes with allochthonous inclusions and nappes of different age and composition was proved, the imbricate–overthrust structure of eastern Primor'e was proposed, and the important role of the Mesozoic accretion in the geodynamic history of the Far East was shown (Krasilov and Parnyakov, 1984; Golozubov and Mel'nikov, 1986; Mikhailov, 1986; Yushmanov, 1986; Mikhailov *et al.*, 1987; Vrublevskii *et al.*, 1988; Parnyakov and Markevich, 1989; Izosov *et al.*, 1990; Golozubov *et al.*, 1992; Khanchuk, 1993). In spite of this, traditional views still prevail especially in economic geology, whereas new results are either distorted or disregarded. For instance, a wide distribution of olistostromes in the Pribrezhnaya SLZ was not highlighted in *Resolutions of the IV Regional Startigraphic Conference* (Vladivostok, 1991). The scheme of the Cretaceous stratigraphy of the SLZ remained unchanged from the early 1980s.

This work is based on the analysis of particular sections of eastern Sikhote Alin (Fig. 1) and their comparison and correlation, which allowed me to show the possibility of using tectono-stratigraphic complexes as basic units for mapping the stratified accretionary prisms of the Pacific framing.

MATERIALS

Khanchuk (1993) revealed that the Sikhote Alin system is composed of terranes of Middle Jurassic–Early Cretaceous accretionary prisms. Distinguished among them (from east to west) are the Pribrezhnyi (Taukhe), Eastern (Zhuravlevka) and Central (Samarka) terranes composed of tectonic units which experienced horizontal displacements (Golozubov *et al.*, 1992; and others).

The Pribrezhnyi terrane is now better understood, and its sections in eastern and western parts differ substantially (Figs. 1 and 2)

In the eastern part, within the Monomakh uplift, a visible fragment of the section begins with the Triassic–Upper Cretaceous Tetyukhe Group (Mikhailov *et al.*, 1987), which is composed of a Middle–Upper Triassic limestone strata (750 m) and a limestone breccia sequence (260 m) bearing Late Triassic (according to Zharnikova and Oleinik) *Neomegalodon triqueter* and Capnuchosphaeridae in the lower part, Jurassic (according to Tikhomirova and Oleinik) *Unuma* sp., *Zhamoidellum ovum* Dum., *Zh. ventricosum* Dum., *Dicantocapsa operculi* Yao, *Cyrtocapsa Mastoidea* Yao, *Tricolocapsa ruesti* Tan., *Archaeodectyomitra apiara* (Rüst), *Tripodictya elengantissima* Vin., *Eucyrtidium ptyctum* Ried et Sanf., *Conosphaera* sp., and others in the middle part, and Jurassic–Early Cretaceous and Early Cretaceous *Stylosphaera* ex. gr. *lanceola* (Parona), *Tripocyclia* sp. cf. *blakei* Pess., *Dictyo-*

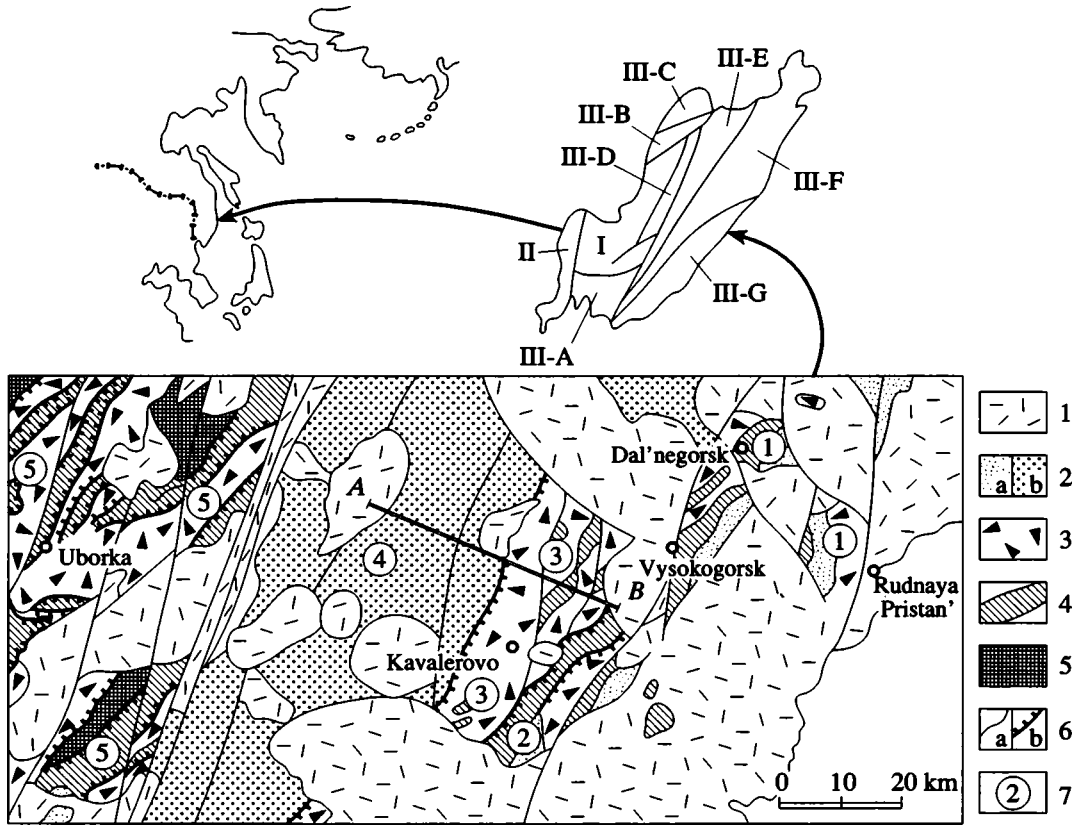


Fig. 1. Localities of sections: (1) postaccretionary extrusive and intrusive complexes; (2) neoautochthon (a), mesoautochthon (b); (3) suballochthon; (4) allochthonous complexes; (5) paleoautochthon; (6) principal strike–slip and normal faults (a), overthrusts and reversed thrusts (b); (7) section numbers. (A–B) line of geological–geophysical section (see Fig. 3).

Numbers on the tectonic scheme of Primor'e (after Bazhanov, 1986) signify: I, Khankai median mass; II, Laoelin–Grodeko geosynclinal folded system; III, Sikhote–Alin geosynclinal folded system with structural–lithologic zones: III–A, Sergeevka and Murav'evo–Dunaiskaya; III–B, Alchansk; III–C, Bikin; III–D, Malinovka; III–E, Central; III–F, Eastern; III–G, Pribrezhnaya.

mitra cf. *cosmoconia* For., *Stichocapsa* cf. *bicacuminata* Rüst, *S. khaltanensis* Kh. Aliev, and others in the upper part of the section. The relationship with underlying rocks is unknown. The Triassic limestones are in contact with younger deposits along the fault zones; limestone breccias interbedding with mudstones gradually overlap limestones and are overlain without visible nonconformity by the lower part of the olistostrome strata. Northwestward, in the central part of the Dal'negorsk ore region, these rocks occur only in the form of olistoliths and olistoplaques within the Early Cretaceous olistostromes making up the "lower" allochthon (Yushmanov *et al.*, 1989).

The olistostrome plays an important part in the structure of the eastern fragment of the Pribrezhnyi terrane, where its thickness ranges up to 1500 m. It consists of a flyschoid matrix with marks of roiling and sub-aqueous slumping, which encloses (or at some levels is devoid of) allochthonous blocks, slumping slabs, and fragments of different age and composition. The matrix yielded remains of the Early Cretaceous (Berriasian–Valanginian) fauna: *Neocomites* sp., *Nuculidae* sp., *Buchia* cf. *fisheriana* (Orb.), *B.* cf. *volgonensis* (Lah.), *B.* cf. *tolli* (Sok.), *Thurmaniceras* sp. cf. *T.* ? *lenkisi* (Anderson), *Variamussium* sp., *Jotrigonia taucheana* Konovalov (identified by Konovalova) and flora *Onychiopsis* sp., *On. psilotoides* (Stokes et Webb) Ward, *Nilssonia schaumburgensis* (Dunk) Nath., *N. densinerris* (Font) Berry, *Otozamites* cf. *klipsteinii* (Dunk) Sew, *Alsophilites nipponensis* (Oishi) Krassil., *Dicksonia arctica* (Prin) Krassil., *D. concinna* Heer, and others (identified by Krasilov and Shorokhova), as well as the Early Cretaceous radiolarians. Flyschoid deposits prevail in the lower part of the section, whereas exotic inclusions are confined to the middle part and major slumping slabs to the upper part (Fig. 2).

Slumping slabs extending for 10–15 km may have a visible thickness of 0.5–1 km. They are composed of repeatedly alternating nappes of the Upper Triassic–Lower Cretaceous Gorbusha Group (Mikhailov *et al.*, 1987, 1989) consisting of marine siliceous and terrigenous rocks related by gradual transitions. The group is subdivided into the Upper Triassic–Upper Jurassic cherts (50–150 m) and the Upper Jurassic–Lower Cre-

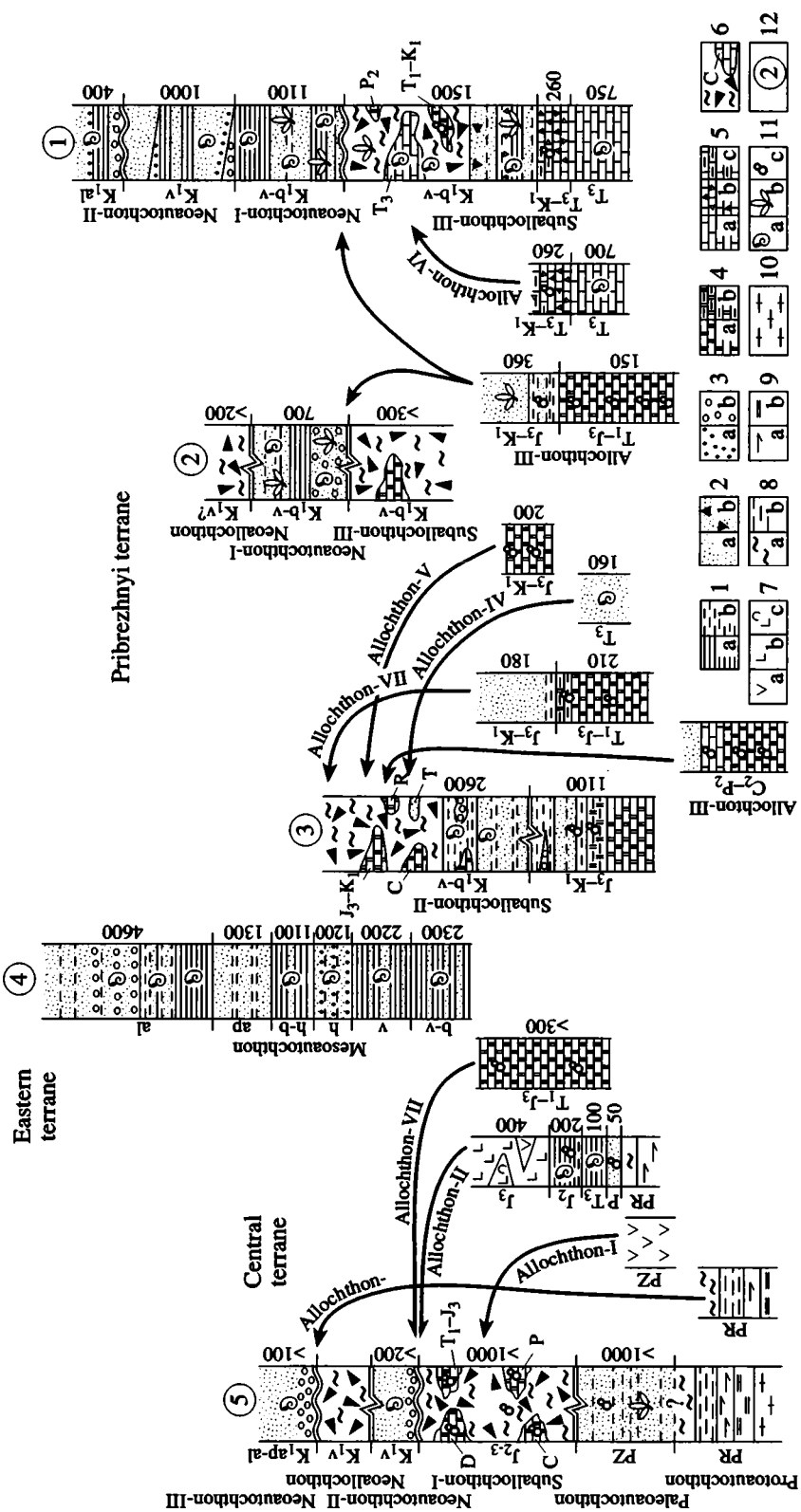


Fig. 2. Correlation columns: (1) siltstones (a), interbedding siltstones and sandstones (b); (2) sandstones (a), sandstones with siltstone detritus (b); (3) gritstones (a), conglomerates (b); (4) cherts (a), siliceous siltstones (b); (5) limestones (a), limestone breccias (b), marls and marly siltstones (c); (6) olistostrome with inclusions; (7) andesites (a), basalts (b), basaltic tuffs (c); (8) microcrystalline (a) and crystalline (b) schists; (9) amphibolites (a), quartzites (b); (10) granite gneiss; (11) localities with fossils: marine invertebrates (a), leaf flora (b), microfauna (c); (12) section numbers.

taceous terrigenous sequence (360 m). The cherts contain successive assemblages of the Early, Middle and Late Triassic conodonts, the Middle and Late Triassic radiolarians, the Middle and Late Jurassic radiolarians, whereas the terrigenous sequence includes the Late Jurassic and Early Cretaceous radiolarians, as well as imprints of the Early Cretaceous ferns *Alsophilites nipponensis* (Oishi) Krassil. The significant stratigraphic interval ranging from the Early Triassic to Early Cretaceous and characteristic of cherts with an extremely low thickness (410–510 m) is a striking fact. The thickness of nappes made up of the Gorbusha Group rocks is usually several times greater, which can be explained by the synsedimentary imbrication of slabs during the sliding of nappes in the Cretaceous time. As a rule, the nappes of the Gorbusha Group overlie with a tectonic contact the Early Cretaceous olistostrome and transgressively underlie the Berriasian–Valanginian terrigenous deposits, which in places overlap other levels of the olistostrome. In addition to the nappes, the olistostrome comprises rounded–isometric and flattened–elongated fragments and blocks (from 1–2 cm to 0.5–1 km in size) of the Triassic, more rarely Permian, limestones, the Triassic–Lower Cretaceous limestone breccias, cherts and sandstones, and spilites.

Allochthonous complexes are conformably overlain by marine terrigenous deposits with the Berriasian–Valanginian bivalves and plant imprints, such as *Buchia* sp., *Beriasella* s. l., *Buchia terebratuloides* (Lah.), *Neocomites* sp. (identified by Kalacheva, Sei, and Konovalova), *Alsophilites nipponensis* (Oishi) Krassil., *Nilssonia* sp., *Onychiopsis* sp., *Podozamites* sp., (identified by Krasilov and Shorokhova), and with the Early Cretaceous radiolarians *Parvicingula cosmoconica* (Foreman), and others (identified by Oleinik). The rocks lack signs of subaqueous slumping and rolling; they are also devoid of exotic blocks and show the prevalence of siltstones, whereas monotonous and flyschoid-type facies are subordinate. This sequence is 1100 m thick, and overlain without visible unconformity, but with local erosion, by a sandstone sequence (1100 m) with the early Valanginian buchias: *Buchia solida* (Lah.), *B.* ex. gr. *visingensis* (Sok), *B.* ex. gr. *inflata* (Toula), *B.* cf. *bulloides* (Lah.), *B. sokolovi* Bodyl., and others (identified by Konovalov). The pre-Upper Cretaceous section of the region is crowned with a 400-m sequence of conglomerates, sandstones, and siltstones with the Albian *Inoceramus concentricus* Park (*Geologiya SSSR*, 1969).

Southeastward, in the southern part of the Kavalerovo ore region, in the Ustinovka River Basin, the section is different (Figs. 1, 2, Section 2). The olistostrome sequence, whose upper part encloses huge slabs of the Gorbusha Group, is overthrust by the 700-m-thick megarhythmic series of conglomerates, gritstones, coarse-grained tophaceous sandstones at the base, alternating with sandstones and siltstones in the middle part and crowned with siltstones of the upper part. The presence of fossil flora and thermophilic shallow-water fauna is a characteristic feature of the series that distinguishes it from the sections of the same level described above and bearing buchias of the deep-water type.

The abundance of fossil flora is proved by the following fact. In 1988, I collected more than 1300 plant imprints of the Berriasian–Valanginian age (identified by Volynets) in one of the localities on the Ustinovka River bank during a short period (3–4 hours); this collection includes *Equisetites* sp. (7 specimens), *Thinnfeldia* sp. (20), *Alsophylites nipponensis* (Oishi) Krassil. (1000), *Coniopteris* sp. (1), *C. burejensis* (Zal.) Sew. (15), *Cladophlebis* sp. (100), *Rodozamites* sp. (3), *Zamiophyllum buchianum* (Ettings.) Nath (200), *Nilssonia schaumburgensis* (Dunk.) Nath. (10), *Cycadolepis* sp. (4), *Nilssonia* ex. gr. *brongniartii* (Mant.) Nath (17), *Otozamites klipstenii* (Dunk.) Sew. (7), *Araucariodendron* sp. (2), and *Sagenopteris* sp. (2). In another outcrop of the same region, I collected about 500 imprints of *Coniopteris arctica* (Pryn.) Samylina (100), *C.* sp. (52), *Onychiopsis psilotoides* (St. et Webb.) Ward (100), *Alsophylites nipponensis* (Oishi) Krassil. (12), *Gleichenites* sp. (11), *Cladophlebis* sp. (118), *Cl.* aff. *triangularis* Oishi (200), *Cl.* cf. *vassilevskae* Vachr. (200), *Nilssonia* cf. *schaumburgensis* (Dunk.) Nath. (2), and *Cycadales* sp. (7).

The megarhythmic series is overlain without unconformity by siltstones with inclusions and blocks of sandstones, siliceous rocks, siliciclastic gritstones and conglomerates, i.e., by mixtites. They bear no fossils, yet the stratigraphic position suggests their Valanginian age.

In the central and eastern parts of the Kavalerovo ore region (Figs. 1, 2, Section 3), according to Golozubov (1986), the Upper Jurassic variegated platy cherts (1100 m) of the Erdagou Formation with intercalations of basalts, siliceous–clayey rocks, siliceous tuffites and fine tuffs occur at the base of the visible part of the section, and are overlain with a gradual transition by a terrigenous sequence of alternating siltstones and sandstones presumably of the Early Cretaceous age. In its composition and structure, the section is similar to the upper parts of the Gorbusha Group section in the Dal'negorsk region. These rocks are overlapped without an angular unconformity or erosion by the sandstone–siltstone flysch, where siltstone abundance increases upsection (Golozubov *et al.*, 1992). Simultaneously, xenogenic inclusions appear in terrigenous deposits, and the flysch grades into olistostrome deposits similar to those in the Dal'negorsk region. The total thickness of this part of the section is 2600 m. The upper part of the olistostrome sequence comprises blocks of the Carboniferous–Permian limestones (for instance, the well-known Arsen'ev Cliff), Upper Triassic sandstones and cherts, and Upper Jurasic–Lower Cretaceous siliceous rocks, which distinguishes these deposits from those in the Dal'negorsk region. A nappe of the "Gorbusha" cherts and terrigenous rocks, which overrides the olistostrome along a gently sloping thrust surface, was found in the Balagannyi Stream area. The

deposits are described in detail in works by Golozubov and coauthors (Golozubov *et al.*, 1986, 1992; Vrublevskii *et al.*, 1988).

It should be emphasized that there are contradictory views on the tectonic zoning of this part of the Sikhote Alin system, namely, on the affiliation of the central and eastern parts of the Kavalerovo region to as suggested by Bersenev (*Geologiya SSSR*, 1969), Golozubov and Mel'nikov's (1986), though they named this zone central, Nazarenko and Bazhanov (1987), and also by Vrublevskii *et al.* (1988), who renamed the zone Pavlovka–Bol'sheussurka. In contrast, Oleinik (1983, 1990) attributed them to the Pribrezhnaya SLZ whereas Golozubov *et al.* (1992) and Khanchuk (1993) included them in the Taukhe terrane. It is caused by the specific lithologic composition of rocks of the region, which differs from that of coeval complexes in both the Pribrezhnaya and Eastern SLZ. The wide distribution of mixtites makes the eastern part of the Kavalerovo region and the Pribrezhnaya SLZ similar. However, the lack of "Kavalerovo" structures northeast of the Yakutinsk volcanostructure, where no important horizontal displacements along tectonic dislocations are assumed, has motivated their assignment to the Eastern SLZ. In all these cases, the boundary between the Pribrezhnaya and Eastern SLZs was placed along the Pribrezhnyi fault traceable as a zone of adjoining thrusts from the Ustinovka River head to the interfluve of Rudnaya and Krasnaya rivers.

However all the contradictions can be eliminated with the eastern part of the Kavalerovo region taken as a giant allochthon, which is thrust over the structures of the Eastern SLZ. Previously, the boundary between them was thought of as an echelon system of the N–S trending strike slip faults associated with gentle (20°–45°) thrusts. Antipova, who interpreted gravimetric profiles across the Kavalerovo region in 1986, reasoned that the boundary could correspond to the zone gently dipping (10°–40°) southeastward and recorded in seismic profiles as a series of reflectors including those with high acoustic impedance, because this zone marks the density gradient in the reconstructed crustal section (Fig. 3). It can represent an extended thrust zone along which the eastern part of the Kavalerovo region is thrust over the Eastern SLZ. In its turn, it is overlapped by the allochthon of the Pribrezhnaya SLZ. It should be pointed out that, according to the interpretation and computer-simulated density models of the section, the layer (3.5–4 km thick) of presumably Paleozoic–Mesozoic (?) sedimentary rocks with a higher density (2.70 g/cm^3) occurs at a depth of 3.5–6 km below the Mesozoic sedimentary rocks of the Pribrezhnaya and Eastern SLZs (the density is 2.65 g/cm^3). Thus, the insignificant thickness of the upper geological–geophysical layer is in conflict with the immense thickness (up to 10–15 km) of stratified bodies of the Pribrezhnaya and Eastern SLZs, leaving no place for them even if we disregard folding and tectonic melange. Further downsection, at a depth of 8–10 km, there are high-density rocks (2.75 g/cm^3), and some authors indentify them as a "granite–metamorphic layer" or as an extension of structures of the Khankai massif at depth (Vasilenko and Klyuev, 1973, and others).

The Eastern or Zhuravlevka terrane, according to Golozubov *et al.* (1992) and Khanchuk (1993), is made up of the Berriasian–Valanginian and Hauterivian–Albian terrigenous–sedimentary rocks. The Central fault, whose strike-slip nature has been proved by Ivanov (1972), is regarded as its western boundary.

The Berriasian–Valanginian deposits, developed mainly in the western part of the terrane, are represented by siltstones, sandstones, members of their rhythmic interbedding, rare interlayers of gritstones, conglomerates, and siliceous–clayey rocks (the Zhuravlevka and Klyuchi formations). Their total thickness is 4500 m. These rocks comprise abundant Berriasian–Valanginian and Valanginian buchias (*Resheniya tret'ego...*, 1982).

The main part of the Eastern SLZ is composed of the Hauterivian–Albian rocks with a total thickness up to 8200 m. Its central part, the Koppi–Luzhki subzone, has a megarhythmic structure. The Hauterivian sandstones with rare siltstone interbeds of the Ust-Kolumbe Formation (1200 m) are overlapped by the Hauterivian–Barremian siltstones with sandstone interbeds of the Primanka Formation (1100 m) and occur at the base of the section of the first megarhythm. The second megarhythm begins with the Aptian sandstones of the Katalevskii Formation (1300 m) and ends with the Albian siltstones of the Divnaya Formation (1000 m). The Albian Svetlovodnaya Formation, displaying rhythmic interbedding of siltstones and sandstones (1200 m), can be referred to the third megarhythm. The section of the central part of the zone is crowned with the lower molasse of the middle–late Albian age, which is represented by interbedding conglomerates, gritstones, sandstones, and siltstones of the Luzhki Formation (2400 m). The foregoing deposits locally contain ammonites, inocerams, aucellinas, and trigonias of corresponding age. The complicated tectonics, poor exposure, scarce fossils, and lithologic similarity of rocks of different time intervals prevent the reliable subdivision and correlation of turbidites of the Eastern terrane, and therefore the stratigraphic sequence of lithologic units and their thickness are poorly known.

Cherts and clayey–siliceous rocks with basalt interbeds were found among terrigenous rocks in the mouth area of Kolumbe River. Tikhomirova identified them as bearing the Late Jurassic radiolarian assemblage, which contradicts the Cretaceous age of these deposits suggested by Nazarenko and Bazhanov (1987). The lithological and paleontological similarity make it possible to consider them as analogues of the Erdagou Formation of the Kavalerovo region. Their position in the section is still unknown. Rounded–isometric chert inclusions (up to 100–150 m) among the Albian (?) siltstones were also found south of this locality, on the

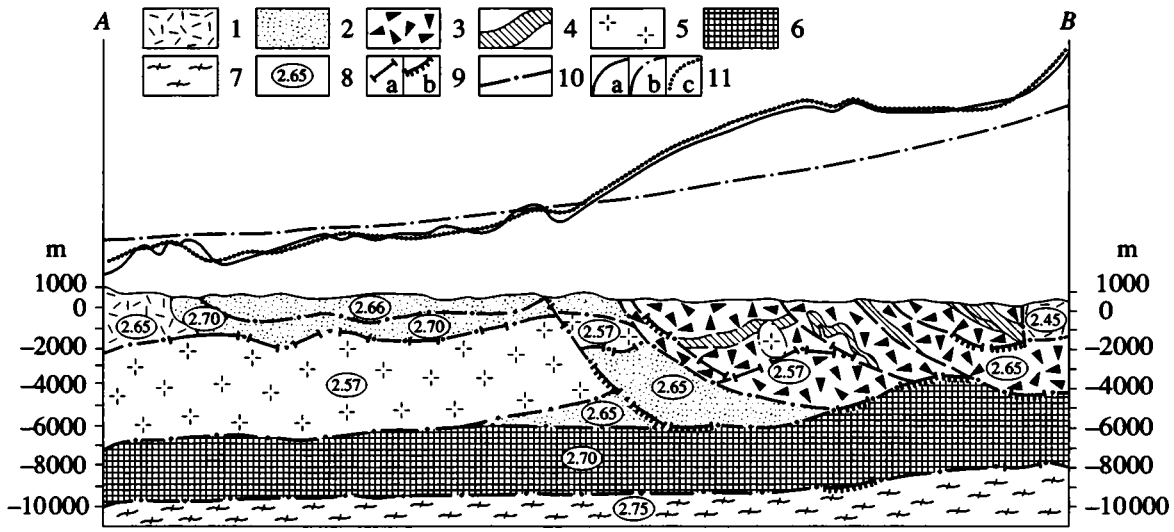


Fig. 3. Schematic geological and geophysical section (for localities see Fig. 1): (1) postaccretionary effusive and intrusive complexes; (2) mesoautochthon; (3) suballochthon; (4) allochthon; (5) buried granitoid intrusions; (6) paleoautochthon; (7) "granite–metamorphic layer" or protoautochthon; (8) average density of anomaly-inducing units; (9) seismic reflectors (a), including those with a high acoustic impedance (b); (10) boundaries of anomaly-inducing units; (11) observed gravity field in Bouguer reduction (σ =2.6 g/cm^3) (a), calculated gravitation values (b), graphs of the regional gravitation component (c).

right bank of Rudnaya River in the ore field of the Smirnov tin–polymetallic deposit. Neither the age of these cherts, nor their relationship with enclosing terrigenous rocks have been revealed.

North of the Dal'negorsk settlement, the Kema subzone (Nazarenko and Bazhanov, 1987) or the Kema terrane (Khanchuk, 1993) of the Eastern SLZ comprises the Aptian–Albian island-arc volcanogenic–sedimentary formation. The Kema subzone is thought to pinch out in the southern flank and to adjoin the Koppi–Luzhki subzone on one side and the Pribrezhnaya SLZ on the other. Taking into account the foregoing facts on linking the Pribrezhnaya and Eastern SLZs in the Kavalerovo region, I assume that the extension of structures of the Kema subzone under the allochthon of the Pribrezhnaya SLZ is not improbable. This is confirmed by Yushmanov's data who has established the thrusting of the Pribrezhnaya SLZ over the Eastern SLZ during the initial evolutionary stage (Hauterivian–Albian) of the Nezhdanka fault, a branch of the Pribrezhnyi fault in the upper reaches of Rudnaya River (Yushmanov, 1985).

The Central SLZ designated by Bersenev (*Geologiya SSSR...*, 1969), Oleinik (1983), Nazarenko and Bazhanov (1987), or referred to as the Western Sikhote Alin zone by Mazarovich (1982), or as the Northwestern zone by Golozubov and Mel'nikov (1986), or as the Samarka terrane by Golozubov *et al.* (1992) and Khanchuk (1993), is the least known of the zones described. This is caused by the complicated structure of the zone, which was a peculiar area during the Mesozoic tectogenesis, into which deverse material, derived from east and west, has been brought to pile chaotically at the base of the continental rise and to be exposed to imbrication and multiple bizarre folding and other dislocations under conditions of the intense collision of terranes of subduction-related accretionary prisms (Khanchuk, 1993). In addition, the main part of the zone was covered by a medium-scale geological survey prior to the appearance of the idea on the wide distribution of chaotic olistostrome complexes in Sikhote Alin; subsequent studies have destroyed the traditional model of the zone structure, but have not produced a new one.

The oldest rocks here are amphibolites, mica and amphibole schists, amphibole–chlorite, chlorite–amphibole, epidote–chlorite, quartz–sericite–chlorite metamorphic schists, as well as quartzites, gneissoid rocks, and migmatites probably of Proterozoic age (Golozubov and Mel'nikov, 1986). Gabbro–diorites, gabbro, amphibolized gabbro similar to the "Sergeev gabbroids" are also referred to the Proterozoic. They occur everywhere either as inclusions, olistoliths and olistoplaques in the Jurassic mixtites, or they make up the base of slabs of the "marginal allochthon" and the upper younger allochthon, which will be described below. In is not improbable that intensely metamorphosed rocks represent the detached masses of the paleo-Khankai massif, whose fragments are probably retained in the basement of the zone. Gabbroids may partially represent relics of the ophiolite association (Khanchuk, 1993).

The age and structural position of the member of greenish gray platy sandstones and siltstones of the Ussuri River upper course is the most intricate problem in the stratigraphy of the Central SLZ. The rocks are easily recognizable and mappable because of their peculiar color, silky luster, foliation, and bed structure;

in addition, they have a graywacke composition (persistently present are epidote, pyroxene, chromite, and olivine in places). Different researchers referred these rocks alternately to the Ariadnoe and Udeko formations ranging in age from the Carboniferous (Belyaevskii *et al.*, 1955) to Early Cretaceous (Golozubov and Mel'nikov, 1986). The structural position of their sequence also remains unknown.

In 1993, I found out in the Levaya Antonovka River Basin that the above-described sequence of green sandstones was tectonically overlapped by the "Okrainka allochthon." In 1953, Gromov found poorly preserved plant fossils in these sandstones at the left bank of Levaya Antonovka River, on the basis of which Krishtofovich reckoned the enclosing rocks to be not older than the Late Devonian, more likely Carboniferous (Belyaevskii *et al.*, 1955). Further westward, in the Levaya Antonovka River head, Eliseeva in 1956 collected foraminifers *Ammodiscus* sp., *Archaediscus* sp., *Endothyra* sp., *Spiroplectammina* (?) sp. from a limestone lens among sandstones and shales, which Sosnina thought to be typical of the Visean to lower Middle Carboniferous. In 1985, Okovityi found foraminifers and crinoids of Middle–Late Carboniferous age (in Nikitina's opinion) in limestone lenses among lithologically identical sandstones of the Bikin River left bank. Lastly, in the stratotype section of the Udeko Formation, whose rocks are indistinguishable from the rocks of the Levaya Antonovka River Basin, Kemkin found conodonts in sandstones interbedding with siltstones on the right bank of the Ussuri River, and Burii identified them as *Neogondolella* cf. *serrata postserrata* (Bender), characteristic of the upper Ufimian–lower Kazanian (Upper Permian). Southerly, in the Stepanov Stream Basin, the same researcher found and Rudenko identified the Late Permian radiolarians *Phaenigosphacra mammilla* Cheng et Wang (Kemkin, 1990). In connection with this, green sandstones of the Central SLZ, previously referred alternately to the Ariadnoe and Udeko formations, can at the present stage of study be considered as Upper Paleozoic deposits, formed due to erosion of metamorphic rocks and basic volcanites of the continental slope of the paleo-Khankai massif. The contact between the sandstones and mixtites of the Samarka Formation is tectonic everywhere, and, as a rule, gabbroids and other fragments of the allochthonous section are thrust over the sandstones. This suggests the autochthonous position of the sandstones.

The Middle-Late Jurassic olistostrome plays an important part in the Central terrane. The olistostrome comprises rocks of the Samarka, Sebuchar, Tudo-Vaka, Eldo-Vaka, Malyanovka and some other formations and rock series distinguished previously, whose age varies from the Late Paleozoic to Cretaceous. These units were distinguished on the basis of previously existing views on the autochthonous position of geologic bodies (*Geologiya SSSR...*, 1969; Belyanskii and Nikitina, 1978; Levashov *et al.*, 1989; Nazarenko and Bazhanov, 1987; and others). However, recent publications show that these sequences represent the Middle–Upper Jurassic giant sedimentary melange with allochthonous blocks of different age ranging in size from centimeters to hundreds of meters and with huge tectonic slabs extending for tens of kilometers (Golozubov and Mel'nikov, 1986; Vrublevskii *et al.*, 1988; Izosov *et al.*, 1990; Kemkin, 1990; and Khanchuk, 1993). The Proterozoic (?) intensely metamorphosed rocks and gabbroids (ophiolites), the Middle–Upper Paleozoic extrusive rocks, the Triassic–Jurassic cherts (similar in composition and age to those of the Gorbusha Group) dominate among fragments, olistoliths and olistoplaques. There are other allochthonous complexes distinguished in the region (Kemkin, 1989; Khanchuk, 1993).

The Okrainka allochthon, extending for hundreds of kilometers in the western part of the terrane from the Kievka River Basin to the left bank of Dorozhnaya River, has a significant place among them. Its considerable extension and thickness (up to 1000 m), the succession of stratigraphic units composing it and persistent in different regions, the specific (as compared to surrounding rocks) lithologic composition and recovered fossils provided the basis for distinguishing an individual Partizansk–Okrainka or Okrainka subzone.

At the base of the Okrainka allochthon, gabbroids, amphibolites, and green shists, metamorphosed to a different degree, rest on metapelites and metabasites, and, as a rule, a zone of mylonitization and cataclasis coincides with the allochthon foot. Peculiar micaceous sandstones of the Izvilinka Formation with the Late Permian foraminifers (identified by Sosnina and Nikitina) overlie these complexes. A thick zone of brecciation and schistosity, as well as tectonic rolls of the Upper Permian limestones, limestone breccias and cataclastic granitoids occur at the base of sandstones. Siltstone interlayers appear in the upper part of sandstones, and they are gradually, without angular unconformity or erosion, overlain by a thick siltstone sequence, which comprises the Norian *Monotis pachypleura* f. *ambiqua, M. pachypleura* f. *aequicostata* (Teller), *M. zabaikalica* (Kipar), *M. semiradiata* Ichik, *M. notabilis* Oleynikov et Payevskaya, *M. ochotica* (Keys), *M. stutiformis, M. pinensis* West., and others (identified by Dorukhovskaya) in the lower part and the Early–Middle Jurassic ammonites and radiolarians in the upper part (*Resheniya...*, 1982). The upper part of the sequence was previously referred to the Okrainka Formation. However, according to our data, it is similar to the Triassic part of the sequence. In this connection, it makes sense either to include the Triassic siltstones into the Okrainka Formation, or to abandon this stratigraphic unit, as it is undistinguishable in lithology from the underlying rocks and can hardly be mapped. The siltstone sequence is conformably overlapped by alkaline basaltoids and their tuffs of the Poga Formation with tuffite interlayers (400 m) attributed to the Late Jurassic. In Afanasieva's opinion (1987), the Poga Formation is coeval to the Malyanovka Formation. The

Okrainka allochthon either is confined to the upper parts of the Samarka olistostrome or overlaps the Paleozoic green sandstones.

All the described complexes of the Central terrane are overlain with a washout by the 200-m-thick, sequence of conglomerates, gritstones, sandstones, and siltstones, comprising abundant imprints of *Buchia bulloides* (Lah.), *B. solida* (Lah.), *B. pacifica* Jeletzky, and others, which confirm the age of the enclosing deposits to be the late Valanginian and probably the uppermost early Valanginian according to Konovalov who has identified the fossils. Golozubov has studied the contact of the sequence with conformably overlying siltstones and silty sandstones, which comprise angular inclusions and blocks of sandstones and cherts not distinct from the "lower" olistostrome. This, along with data on Ustinovka River in the Pribrezhnyi terrane, suggests at least two time intervals of formation of the Cretaceous olistostromes. According to Vrublevskii and coauthors (1988), the formation of the upper allochthonous slab of "gabbroids" with mixtites at the base, which overlies the Poga Formation basaltoids and the Triassic siltstones of the Okrainka allochthon on the Pavlovka River right bank, corresponds to the Valanginian.

The pre-Upper Cretaceous section of the terrane is crowned with a sandstone, siltstone, conglomerate, and conglobreccia sequence, 100 m thick and overlying with angular unconformity the older rocks (the Sokolovka Formation). The sequence yielded the Aptian–Albian fauna.

DISCUSSION

As follows from the analysis of the material presented and the investigation history of the Sikhote Alin regions described, the subdivision and mapping of chaotic complexes by traditional stratigraphic methods are impossible. All efforts of the layer-by-layer identification of stratigraphic units disregarding their tectonic nature have already resulted in misunderstanding of the Sikhote Alin geology and caused a situation in which any reconstruction based on traditional methods goes out of date well before having a chance to be published. This is true in particular of resolutions of the abovementioned IV Stratigraphic Conference, as well as of some regional cartographic material, the work on which has not yet even been completed.

In this connection, it is suggested that stratigraphic methods should be abandoned when subdividing olistostromes, and tectono-stratigraphic complexes should be taken as basic units when mapping them. This in turn entails an abandonment of the structural–lithologic zones, which should be transformed into regular series of tectono-stratigraphic complexes successively colliding with the continental margin. Autochthon, suballochthon, and allochthon are distinguished as basic type members of these complexes.

The autochthon is to be considered as a structure that has not experienced displacement in the course of synsedimentary or postsedimentary thrusting or nappe movements, unrelated to strike-slip tectonics. According to age and structural position, the autochthonous complexes are subdivided into proto-, paleo-, meso-, and neoautochthons. The protoautochthon is suggested to include hypothetical blocks of high-density rocks at a depth related to the Khankai massif. These rocks are known in the Middle–Late Jurassic olistostrome. The paleoautochthon comprises the Paleozoic green sandstones, tectonically overridden by olistostrome or directly by the "Okrainka" allochthon. At the same time, inclusions of such sandstones are not found in the olistostrome. Under the mesoautochthon, I mean the Early Cretaceous rocks of the Eastern SLZ, over which rock masses of the Kavalerovo and Dalnegorsk regions were thrust in the latest Early Cretaceous (but prior to significant strike-slip dislocations). The rocks are assumed to form in a flysch trough, opened in a northeastward direction and bordered on the west and east by land.

The neoautochthon comprises deposits transgressively overlapping the allochthonous complexes as if sealing them after nappes have been formed. Several units are distinguished among neoautochthons by time of their formation: I (Berriasian–Valanginian), II (Valanginian), III (Aptian–Albian), IV (Albian). It is easily seen from Fig. 2 that Neoautochthon I appears to be simultaneously the autochthon for the neoallochthon in the Pribrezhnyi terrane (Section 2)..

Suballochthons, which comprise chaotic complexes of the Middle–Late Jurassic (Suballochthon I), Late Jurassic–Valanginian (Suballochthon II), Late Triassic–Valanginian (Suballochthon III), plays an important part in the structure of Sikhote Alin. To explain the formation of these complexes, Khanchuk (1993) has offered the subduction model implying that, when an oceanic plate is plunging into a deep-water trench near the continental margin, a chaotic complex develops here due to disintegration both of the plate itself with sediments accumulated on it and of the overhanging continental slope. It is likely that in reality the subduction-type mixtites, subaqueous slumping deposits, and tectogenic olistostromes were brought into a single geological area to be buried together in the turbidite matrix, assuming that olistostromes are formed due to thrusting and destruction of frontal nappe parts and different subwater scarps. The successive accretion of terranes does not yet signify the cessation of the motion of nappes still sliding upward along the continental slope for a time.

As a first approximation, eight units (I–VIII) are distinguished among allochthons according to the time of their formation. Golozubov and coauthors (1992) pointed out that, occupying regular structural positions, they may sometimes act as "key horizons" resembling stratigraphic units. Allochthon I composed of Paleozoic

effusives seems to be the oldest among them all. It is not improbable that it moved from the northwest to southeast like Allochthon VIII consisting of intensely metamorphosed sedimentary and igneous rocks similar to those in the Khankai massif. Allochthon II is a complex of stratigraphic units previously distinguished as the Okrainka SLZ. Allochthons I and II are found only within the Central terrane.

Allochthons III (the Carboniferous–Permian limestones, cherts and sandstones), IV (the Triassic *Monotis* sandstones), and V (the Upper Jurassic–Lower Cretaceous cherts and clayey rocks) are revealed only in the eastern part of the Kavalerovo region, where they are confined to Suballochthon II. It is easily seen that rocks of Allochthon V are of a dual nature, simultaneously composing the visible base of Suballochthon II (Fig. 2). Allochthon VI (the Triassic limestones and the Triassic–Jurassic limestone breccias) is distinguished only in the Dal'negorsk region. The same deposits are found here to represent root zones of Suballochthon III (Mikhailov *et al.*, 1987).

Allochthon VII, confined to the upper part of the olistostrome complex and, as a rule, overlain by the neoautochthon, is the most widespread in the region. It consists of the Gorbusha Group deposits and their fragments, i.e., Triassic–Jurassic cherts and Jurassic–Upper Cretaceous terrigenous rocks. The allochthon makes up vast nappes in all parts of accretionary prisms of the southeastern framing of the Khankai massif, as well as in the Bikinskaya SLZ (Fig. 1). At present, such a wide distribution of specific rocks can be explained by no other mechanism than thrusting.

Allochthon VIII appears to be the youngest among all the units. It is composed of "gabbroids" thrust over the neoallochthon in the right bank of Shumnaya River (Golozubov and Mel'nikov, 1986; Vrublevskii *et al.*, 1988).

Mixtites, overlying the deposits of the neoautochthon in the Ustinovka River Basin (Fig. 2, Section 2) and on the right bank of Pavlovka River (Fig. 2, Section 5), are attributed to the neoallochthon. The presence of such deposits is indicative of the multi-stage thrusting process, which was revived repeatedly over the course of the Middle Jurassic–Early Cretaceous history of Sikhote Alin.

CONCLUSION

The data presented in the work and in most of the publications mentioned above prove the necessity of revising common views on the geologic structure of Sikhote Alin and the approaches for studying this and other regions with a wide distribution of olistostromes. In particular, it is necessary to abandon the commonly accepted principles of the stratigraphic subdivision of chaotic associations, to cancel the distinguishing of structural–lithologic zones as static units inconsistent with real geological processes, and to use tectono-stratigraphic complexes as basic units for mapping. Among such units, which have been distinguished in southeastern Sikhote Alin, are proto-, paleo-, meso-, and neoautochthon, suballochthon and neoallochthon, and allochthons I–VIII, which make up regular series and associations of the region and reflect a complicated history of layered accretionary prisms of the northwestern Pacific margin.

REFERENCES

Afanas'eva, V.M., Relationship of the Malyanovka and Poga Formations in the Main Anticlinorium of Southern Sikhote Alin, in *Geosinklinal'nye osadochno–vulkanogennye formatsii Sovetskogo Dal'nego Vostoka* (Geosynclinal Volcanosedimentary Formations of the Soviet Far East), Vladivostok: Dal'nevost. Otd. Akad. Nauk SSSR, 1987, pp. 23–32.

Belyanskii, G.S. and Nikitina, A.P., The Samarka and Sebuchar Formations of the Main Anticlinorium of Sikhote Alin (Primor'e), in *Biostratigrafiya yuga Dal'nego Vostoka (proterozoi)* (Proterozoic Biostratigraphy of Southern Far East), Vladivostok: Dal'nevost. Nauch. Tsentr Akad. Nauk SSSR, 1978, pp. 23–25.

Belyaevskii, N.A., Gromov, Yu.Ya., Eliseeva, V.K., and Putintsev, V.K., *Geologiya Primorskogo kraya: Ob"yasnitel'naya zapiska k geologicheskoi karte Primorskogo kraya masshtaba 1 : 500 000* (Geology of Primor'e: Explanatory Note for the Geological Map of Primor'e, Scale 1 : 500 000), Moscow: Gosgeoltekhizdat, 1955.

Geologiya SSSR: Tom 32. Primorskii krai, chast' 1 (Geology of the USSR: Vol. 32. Primor'e, Pt. 1) Moscow: Nedra, 1969.

Golozubov, V.V. and Mel'nikov, N.G., *Tektonika geosinklinal'nykh kompleksov Yuzhnogo Sikhote Alinya* (Tectonics of Geosynclinal Complexes of Southern Sikhote Alin), Vladivostok: Dal'nevost. Nauch. Tsentr Akad. Nauk SSSR, 1986.

Golozubov, V.V., Khanchuk, A.I., Kemkin, I.V., *et al.*, The Taukhe and Zhuravlevka Terranes (Southern Sikhote Alin), *Preprint of Russ. Acad. Sci., Far East Division*, Vladivostok, 1992.

Ivanov, B.A., *Tsentral'nyi Sikhote–Alinskii razlom* (Central Sikhote-Alin Fault), Vladivostok: Dal'nevost. Knizhn. 1972.

Izosov, L.A., Levashov, G.B., Bedokurov, E.I., *et al.*, Mesozoic Ore-Bearing Olistostrome Formation of Sikhote Alin and its Tectonic Position in the Sea of Japan Region, *Preprint of Russ. Acad. Sci., Far East Division*, Vladivostok, 1990.

Kemkin, I.V., Olistostromes in Accretionary Complexes of Southern Sikhote Alin, *Cand. Sci. (Geol.) Dissertation*, Vladivostok: Far East Geol. Inst., 1989.

Kemkin, I.V., The Genesis, Morphostructural Position and Age of Deposits of the Udeko Formation in Southern Sikhote Alin, in *Litogenez i rudoobrazovanie v drevnikh i sovremennykh morskikh basseinakh Dal'nego Vostoka* (Lithogenesis and Ore Formation in Past and Recent Sea Basin of Far East), Vladivostok: Dal'nevost. Otd. Akad. Nauk SSSR, 1990, pp. 29–34.

Khanchuk, A.I., Geological Structure and History of the Continental Rim of Northwestern Pacific, *Doctoral. (Geol.) Dissertation*, Moscow: Geol. Inst. Russ. Acad. Sci., 1993.

Krasilov, V.A. and Parnyakov, V.P., The Tetyukhe Ore-Bearing Formation—the Olistostrome Complex, *Dokl. Akad. Nauk SSSR*, 1984, vol. 227, no. 3, pp. 669–671.

Levashov, G.B., Rybalko, V.I., Izosov, L.A., *et al.*, *Tektonomagmaticheskie sistemy akkretsionnoi kory (Sikhote Alin)* (Tectono–Magmatic Systems of the Accretionary Crust: Sikhote Alin), Vladivistok: Dal'nevost. Otd. Akad. Nauk SSSR, 1989.

Mazarovich, A.O., *Tektonicheskoe razvitie Yuzhnogo Primor'ya v paleozoe–rannem mezozoe* (Tectonic History of Southern Primor'e in the Paleozoic–Early Mesozoic), Moscow: Nauka, 1985.

Mikhailov, V.A., New Data on the Composition and Structure of the Berriasian–Valanginian Deposits of the Pribrezhnaya Zone, in *Novye dannye po stratigrafii Primorskogo sektora Yaponomorskogo regiona* (New Data on the Stratigraphy of the Primor'e Sector of the Sea of Japan Region), *Preprint of the Far East Res. Center, Acad. Sci. USSR*, 1986, pp. 36–47.

Mikhailov, V.A., Vrublevskii, A.A., and Yushmanov, Yu.P., Structure and Conditions of Formation of Nappes in the Pribrezhnaya Zone, Primor'e, *Tikhookean. Geol.*, 1987, no. 1, pp. 83–91.

Mikhailov, V.A., Volokhin, Yu.G., Parnyakov, V.P., and Oleinik, L.M., On the Age and Scope of the Gorbusha Group in the Pribrezhnaya Zone of the Sikhote Alin Folded Region, *Tikhooken. Geol.*, 1989, no. 4, pp. 70–77.

Nazarenko, L.F. and Bazhanov, V.A., Geology of Primor'e: Part I. Stratigraphy, *Preprint of the Far East Res. Center, Acad. Sci. USSR*, 1987.

Nazarenko, L.F. and Bazhanov, V.A., Geology of Primor'e: Part III. Principal Features of the Tectonics and Evolution, *Preprint of the Far East Res. Center, Acad. Sci. USSR*, 1987.

Oleinik, Yu.N., Tectonic Zoning of Primor'e, *Tikhookean. Geol.*, 1983, no. 1, pp. 11–19.

Parnyakov, V.P. and Markevich, V.S., On the Age of Olistostrome Strata of the Dal'negorsk Region, *Tikhookean. Geol.*, 1989, no. 1, pp. 47–52.

Resheniya tret'ego mezhvedomstvennogo regional'nogo stratigraficheskogo soveshchaniya po dokembriyu i fanerozoyu Dal'nego Vostoka SSSR (Resolutions of III Interdepartmental Regional Conference on the Precambrian and Phanerozoic Stratigraphy of the USSR Far East, Vladivostok, 1978), Magadan: Mezhved. Stratigr. Kom. USSR, 1982.

Vasilenko, V.P. and Klyuev, V.K., Deep Structure of Eastern Primor'e and Regularities in Distribution of Tin Deposits, in *Zakonomernosti razmeshcheniya poleznykh iskopaemykh* (Regularities in Distribution of Mineral Deposits), Moscow: Nauka, 1973, pp. 175–182.

Vasil'kovskii, N.P., *Paleogeologiya severo–vostoka Azii* (Paleontology of Northeastern Asia), Moscow: Nauka, 1984.

Vrublevskii, A.A., Mel'nikov, N.G., Golozubov, V.V., *et al.*, *Mikstity Sikhote–Alinskoi skladchatoi sistemy* (Mixtites of the Sikhote Alin Folded System), Vladivostok: Dal'nevost. Otd. Akad. Nauk SSSR, 1988.

Yushmanov, Yu.P., On Tectonic Movements along the Nezhdanka Fault (Primor'e), *Tikhookean. Geol.*, 1985, no. 3, pp. 117–120.

Yushmanov, Yu.P., Synsedimentary Nappes of the Pribrezhnaya Zone of Eastern Sikhote Alin by the Example of the Dal'negorsk Ore Region, *Tikhookean. Geol.*, 1986, no. 3, pp. 99–107.

Yushmanov, Yu.P., Terebilo, V.I., Zhuravlev, V.N., *et al.*, Synsedimentary Nappes and Regularities in Localization of Polymetallic Mineralization in the Dal'negorsk Region, in *Geologicheskie usloviya lokalizatsii endogennogo orudeneniya* (Geological Conditions for Localization of Endogenic Mineralization), Vladivostok: Dal'nevost. Otd. Akad. Nauk SSSR, 1989, pp. 149–158.

Stratigraphy and Geological Correlation, Vol. 5, No. 4, 1997, pp. 401–407. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 4, 1997, pp. 95–100.
Original Russian Text Copyright © 1997 by Vorozhbitov.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

BRIEF COMMUNICATIONS

First Finds of Silurian–Lower Devonian Conodonts in Southern Mongolia and Their Biostratigraphic Implications

A. M. Vorozhbitov

Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia

Received April 4, 1996

Key words: *conodonts, brachiopods, zone, Silurian, Devonian, Mongolia*

Silurian and Early Devonian conodonts were not known in Mongolia until recently. The first Early Devonian zonal conodonts *Icriodus woschmidti* (Ziegler) were reported earlier (Rozman *et al.*, 1991; Vorozhbitov, 1992). In 1989, I, under the direction of Kh.S. Rozman, collected specimens for conodont analysis from several Silurian–Lower Devonian sequences of western, eastern, and southern Mongolia, which Rozman had studied in 1983–1987 (Fig. 1a).

In Silurian samples, conodont remains are scarce. Only occasional sections contained, at some levels, stratigraphically significant conodont specimens. Such fauna paucity is due to an unfavorable habitat (dominant organisms are Stromatoporoidea, Rugosa, Tabulata, Crinoidea, and Brachiopoda), and sedimentation conditions for conodonts. A high sedimentation rate acccounts for a very low concentration of conodont elements per unit of rock volume. Conodonts are mostly confined to calcareous nodules and limestone interlayers of essentially terrigenous, relatively deepwater parts of the sections.

Lower Devonian samples were richer in conodonts than Silurian rocks, and, significantly, they contained zonal species. In total, twelve multielement species were identified in the Silurian, and, four were recorded in the Devonian.

Below, will be found a brief description of three sections two Silurian and one Devonian, that contain the most representative conodont elements. Brachiopods were defined by Kh.S. Rozman.

Section 1: Southern Mongolia, Gobi Altai, the Dzhinsetu-Ula Range, 30–40 km southeast of the Shine-Dzhinst and 0.6 km southeast of Shara-Chulut-Khuduk (Figs. 1a and 1b). The following rocks are exposed north of the fault, along which the Lower Silurian Gobi strata border the Upper Ordovician Syrin beds:

Bed 1. Intercalation (5–10 cm) of siltstones with fine-grained greenish gray, light blue-gray thin to medium-layered sandstones. There are 3 interbeds of yellowish orange argillaceous limestone in the upper part. The upper interbed contains the conodonts: *Pterospathodus pennatus pennatus* (Walliser), *Distomodus staurognathoides* (Walliser), *Ozarkodina* cf. *polinclinata* (Nicoll and Rexroad), *Pseudoneothodus tricornis* Drygant, *Panderodus recurvatus* (Rhodes) (Spec. 89-11/1). The thickness is 60 m.

Bed 2. Sandstones green, fine to medium-grained, massive, thick-platy. The thickness is 10 m.

Bed 3. Green siltstones with nodules and lenticular gray limestone interbeds. Isometric blocks (1–2 m) and interlayers of gray, massive, marmoraceous limestone occur at the base of the bed. For 150 m along the trend, the bed contains a limestone block with Upper Ordovician *Catenipora*. Lenticular limestone interlayers were found to contain brachiopods, among them: *Isorthis disjuncta* Vladimirskaya, *Dolerorthis rustica* (Sowerby), *Platyorthis tchimedi* Rozman, *Leangella scissa brevimya* Rozman, *Leptaena kysiltrchiraensis* Kulkov, *Mongolistrophia ludmilae* Rozman, *Strophomena* sp., *Stegerhynchus* ex gr. *St. concinna* (Savage), *Glassia tenella* Williams, *Eospirifer radiatus* (Sowerby), *Eospirifer* ex gr. *E. tuvaensis* (Tchernychev). The limestone interlayer occurring close to the base of the bed contains conodonts, among them: *Pterospathodus pennatus procerus* (Walliser), *P. praeamorphognathoides* Vorozhbitov, and *Carniodus carnulus* Walliser (Spec. 89-11/2a). The thickness is 10–12 m.

Bed 4. Intercalation of brown-red, crinoid–detrite, intensely weathered limestones with isolated interlayers of green siltstones. Brachiopods: *Dolerorthis rustica* (Sowerby), *Platyorthis tchimedi* Rozman, *Leptaena kysiltchiraensis* Kulkov, *Mongolistrophia ludmilae* Rozman, *Stegerhynchus angaciensis* Tchernychev, and *Eospirifer* ex gr. *E. tuvaensis* (Tchernychev). The thickness is 10 m.

The total thickness of the section is about 90 m.

Section II: southern Mongolia, the western border of the Mandalobin massif, the Mushugai-Khuduk well

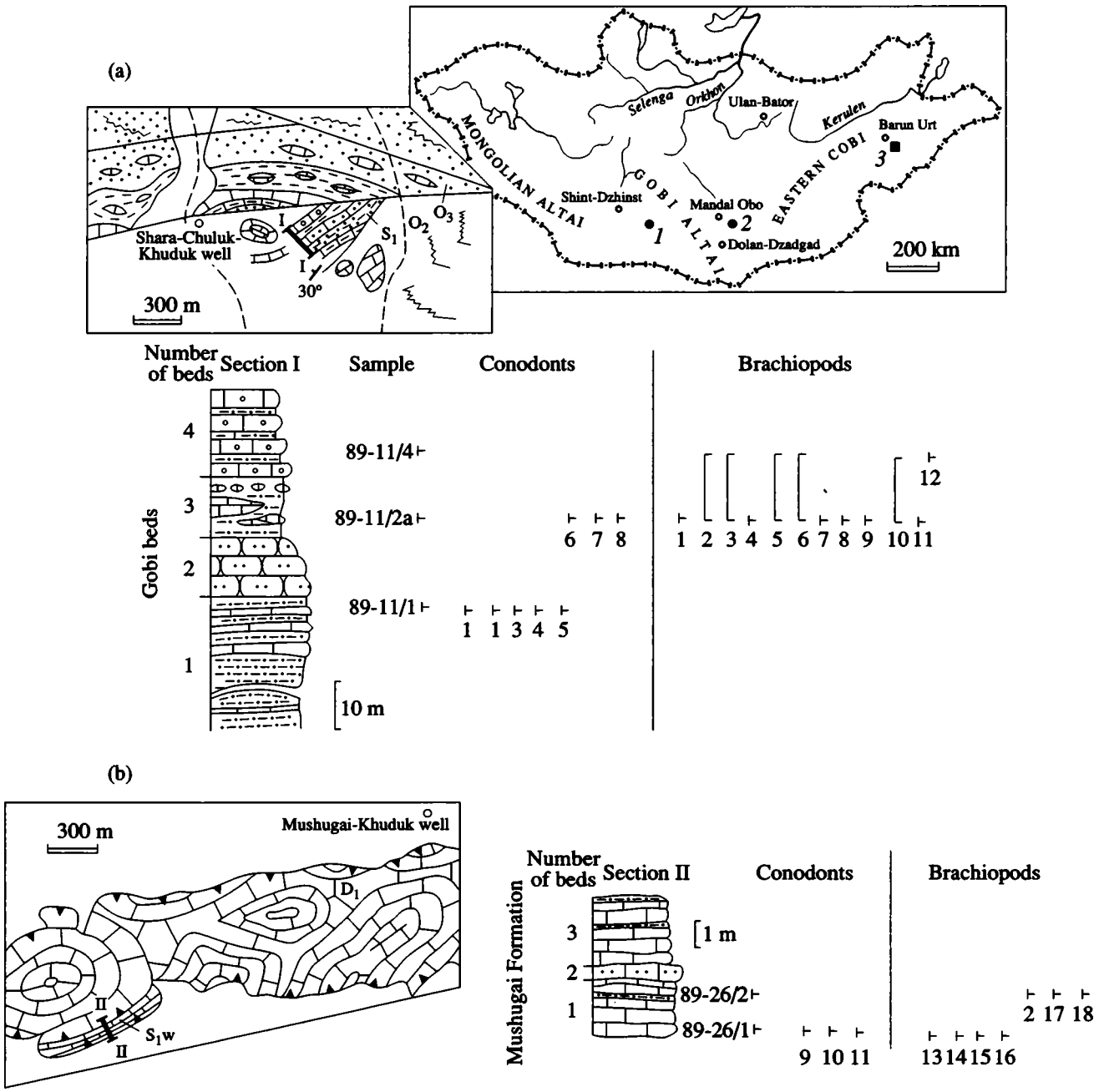


Fig. 1. Position of the studied Silurian and Devonian sections of Mongolia (a), in which conodonts were identified: [(*1–2*) Silurian and (*3*) Devonian sections], and schemes of the geological structure (b) in areas of the Shine-Dzhinst and Mandal-Obo salmons (after Kh.S. Rozman and Ch. Minzhin) with the distribution of conodonts and brachiopods in Sections I and II. Conodonts: (1) *Pterospathodus pennatus pennatus* (Wall.); (2) *Distomodus staurognathoides* (Wall.); (3) *Ozarkodina* cf. *polinclinata* (Nicoll and Rexroad); (4) *Pseudoneothodus tricornis* Drygant; (5) *Panderodus recurvatus* (Rhodes); (6) *Pterospathodus pennatus procerus* (Wall.); (7) *P. praeamorphognathoides* Vorozh.; (8) *Carniodus carnulus* Wall.; (9) *Ozarcodina excavata excavata* (Branson and Mehl); (10) *Kockelelella ranuliformis* (Wall.); (11) *Pseudoneothodus beckmanni* (Bischoff and Sannemann). Brachiopods: (1) *Isorthis disjuncta* Vlad.; (2) *Dolerorthis rustica* (Sow.); (3) *Platyorthus tchimedi* Rozm.; (4) *Leangella scissa brevimya* Rozm.; (5) *Leptaena kysiltschiraensis* Kulk.; (6) *Mongolistrophia ludmilae* Rozm.; (7) *Stegerhynchus* ex gr. *St. concinna* (Sow.); (8) *Glassia tenella* Will.; (9) *Eospirifer radiatus* (Sow.); (10) *Eospirifer* ex gr. *Eosp. tuvaensis* (Tchern.); (11) *Strophomena* sp.; (12) *Stegerhynchus angaciensis* Tchern.; (13) *Tannuspirifer pedaschencoi* (Tchern.); (14) *Stegerhynchus* cf. *St. borealis*; (15) *Dolerorthis* sp.; (16) *Conchidium* sp.; (17) *Isorthis* cf. *Is. markovskii* (Tchern.); (18) *Conchidium* sp. Other sympols as in Fig. 2.

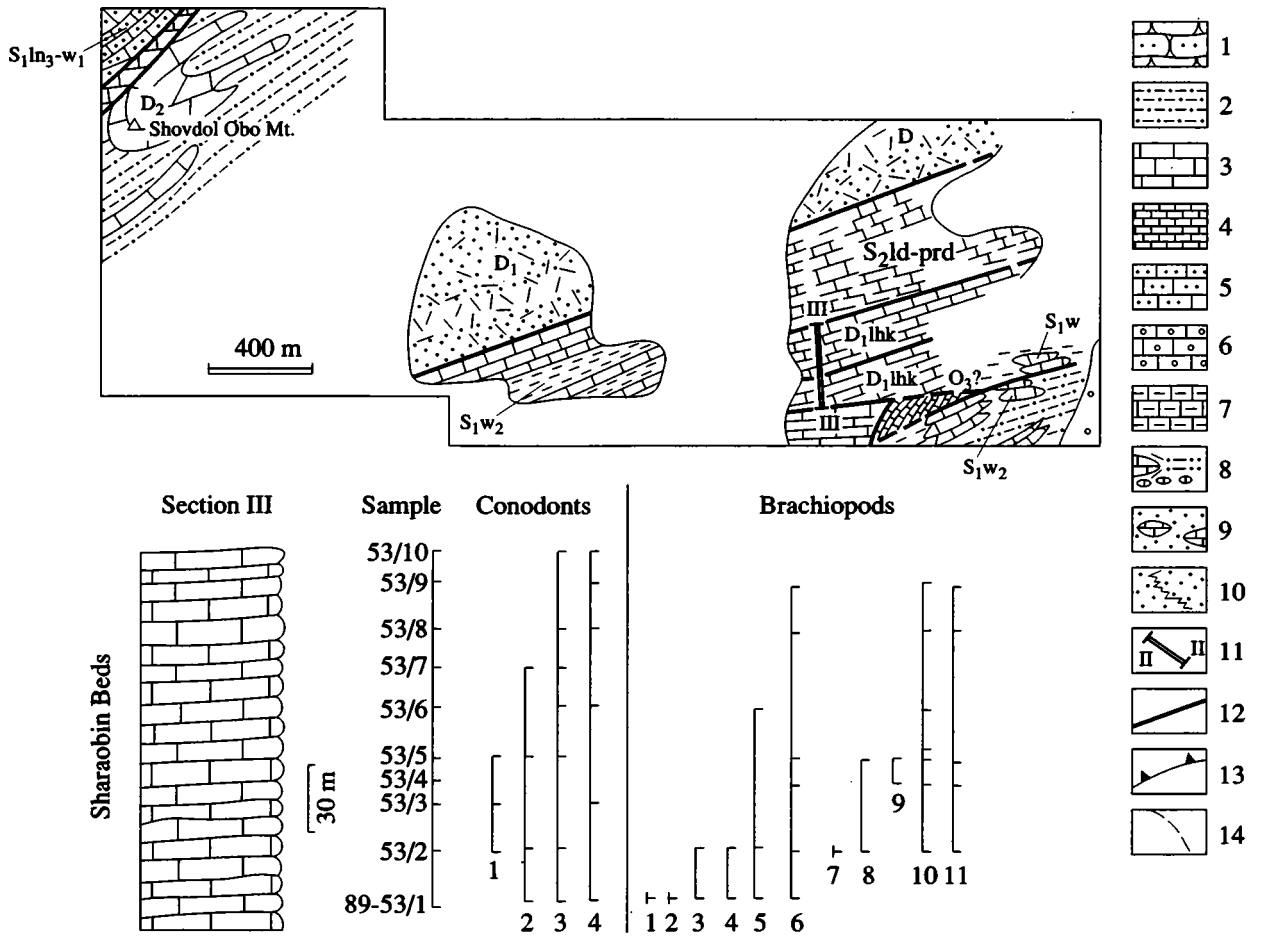


Fig. 2. Scheme of the geological structure of the Shovdol-Obo mountain area (after Kh.S. Rozman, Ch. Minzhin, and L.I. Popeko), with the distribution of conodonts and brachiopods in Section III.

Conodonts: (1) *Panderodus* sp.; (2) *Parapelekysgnathus svetlanovae* Vorozh.; (3) *Icriodus woschmidti* cf. *J. w. transiens* Carls and Gandle; (4) *Ozarcodina remscheidensis* (Ziegler). Brachiopods: (1) *Shovdolella schovdolensis* Rozm.; (2) *Altaella contorta* Kulk.; (3) *Rhynchospirina semiradzkii* Kozl.; (4) *R. alekseevi* Grunt.; (5) *Mesodouvillina* (P.) *costatula* (Barr.); (6) *Protathyris praecursor* Kozl.; (7) *P. bortegensis* Grunt; (8) *Pseudoprotathyris infantilis* Kozl.; (9) *Howellella angustiplicata* Kozl.; (10) *Iridistrophia praeumbracula* (Kozl.); (11) *Microsphaeridiorhynchus* ex gr. *M. nucula* (Sow.). Rocks: (1) sandstone; (2) siltstone; (3) calcareous, organogenic-clastic limestone; (4) calcareous fine-laminated limestone; (5) sandy limestone; (6) crinoidal limestone; (7) coral limetone; (8) siltstone wih limestone intercalations and nodules; (9) sandstone with limestone lenses and intercalations; (10) tuffaceous shale and tuffstone; (11) section lines and numbers; (12) faults; (13) overthrust boundaries; (14) valleys of temporal water flows (Sai).

surroundings, 60 m to the south from the foot of the limestone ridge (Fig. 1b):

Bed 1. Intercalated a) gray fine-grained dense limestones, (b) gray to pink-gray and yellow-gray medium-grained limestones with occasional thin (up to 1 cm) interlayers of yellow-green siltstones, and (c) pink-yellow clastic thin-bedded (0.2-0.5 cm) limestones. Brachiopods of the bed are: *Dolerorthis* sp., *Conchidium* sp., *Stegerhynchus* cf. *St. borealis* (Buch.), and *Tannuspirifer pedaschenkoi* (Tchernychev). Conodonts are identified at the level of 0.5 m from the bed foot, among them: *Ozarkodina excavata excavata* (Branson and Mehl), *Kockellella ranuliformis* (Walliser), and *Pseudoneothodus beckmanni* (Bischoff and Sannemann) (Spac. 89-26/1). The thickness is 2.5 m.

Bed 2. Gray crinoidal brecciated limestones. Clastic (3–5 cm) limestones are chaiotically distributed in a sand–limestone matrix. Brachiopod fauna includes *Dolerorthis* ex gr. *D. rustica* (Sowerby), *Isorthis* cf. *Js. markovskii* (Tchernychev), and *Conchidium* sp. (Spec. 89-26/2). The thickness is 0.5 m.

Bed 3. Intercalated limestones as in Bed 1. The thickness is 3 m.

The total thickness is 6 m.

The Lower Devonian rocks of the Mandalobin Formation rest on these beds with a tectonic unconformity.

Section III: southeastern Mongolia, 40 km south of Barun-Urt town, 3.3 km southeast of Shovdol-Obo mountain (Fig. 2). The section is the parastratotype of the Sharaobin beds. The intercalation of limestones

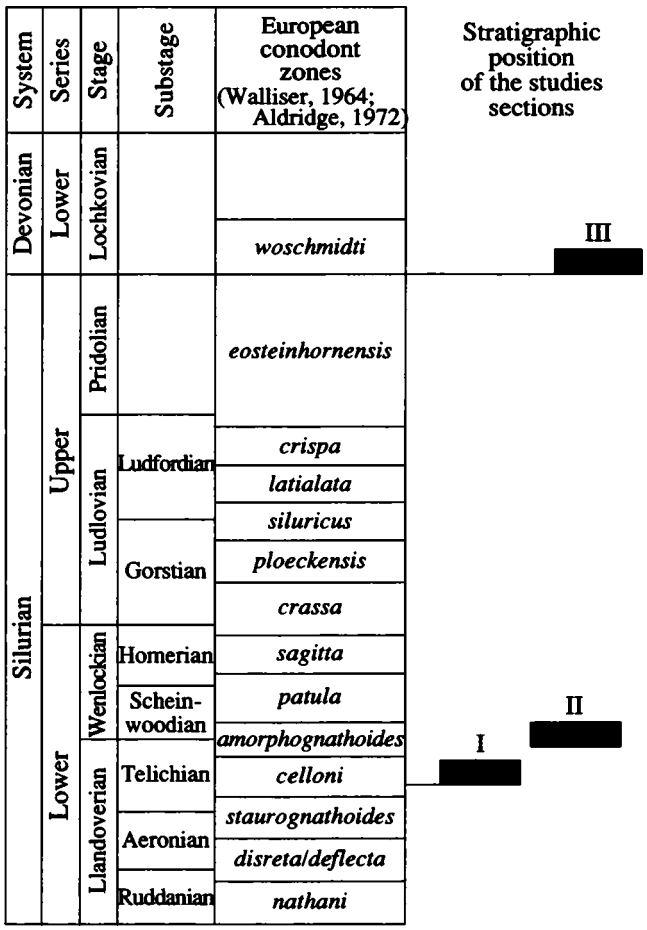


Fig. 3. Correlation of the studied sections with the Silurian–Lower Devonian conodont zonation in Europe.

(light to dark gray and bluish at the weathered surface, layered (5–10 cm), organoclastic) is recorded within the studied striping trench. The following brachiopods have been identified here: *Howellella angustiplicata* Kozl., *Shovdolella shovdolensis* Rozm., *Mesodouvillina* (P.) *costatula* (Barr.), *Altaella contorta* Kulk., *Rhynchospirina semiradzkii* Kozl., *R. alekseevi* Grunt., *Iridistrophia praeumbracula* (Kozl.), *Microspaeridiorhynchus* ex gr. *nucula* (Sow.), *Protathyris praecursor* Kozl., *Pseudoprotathyris infantilis* Kozl., and *Protathyris bortegensis* Grunt. (Rozman, 1991). Conodonts are identified at 10 levels and represented by *Icriodus woschmidti* cf. *I. woschmidti transiens* Carls and Gandle, *Ozarcodina remscheidensis* (Ziegler), and *Parapelekysgnathus svetlanovae* Vorozhbitov, *Panderodus* sp. (Spec. 89-53/1-10). The thickness is 300 m.

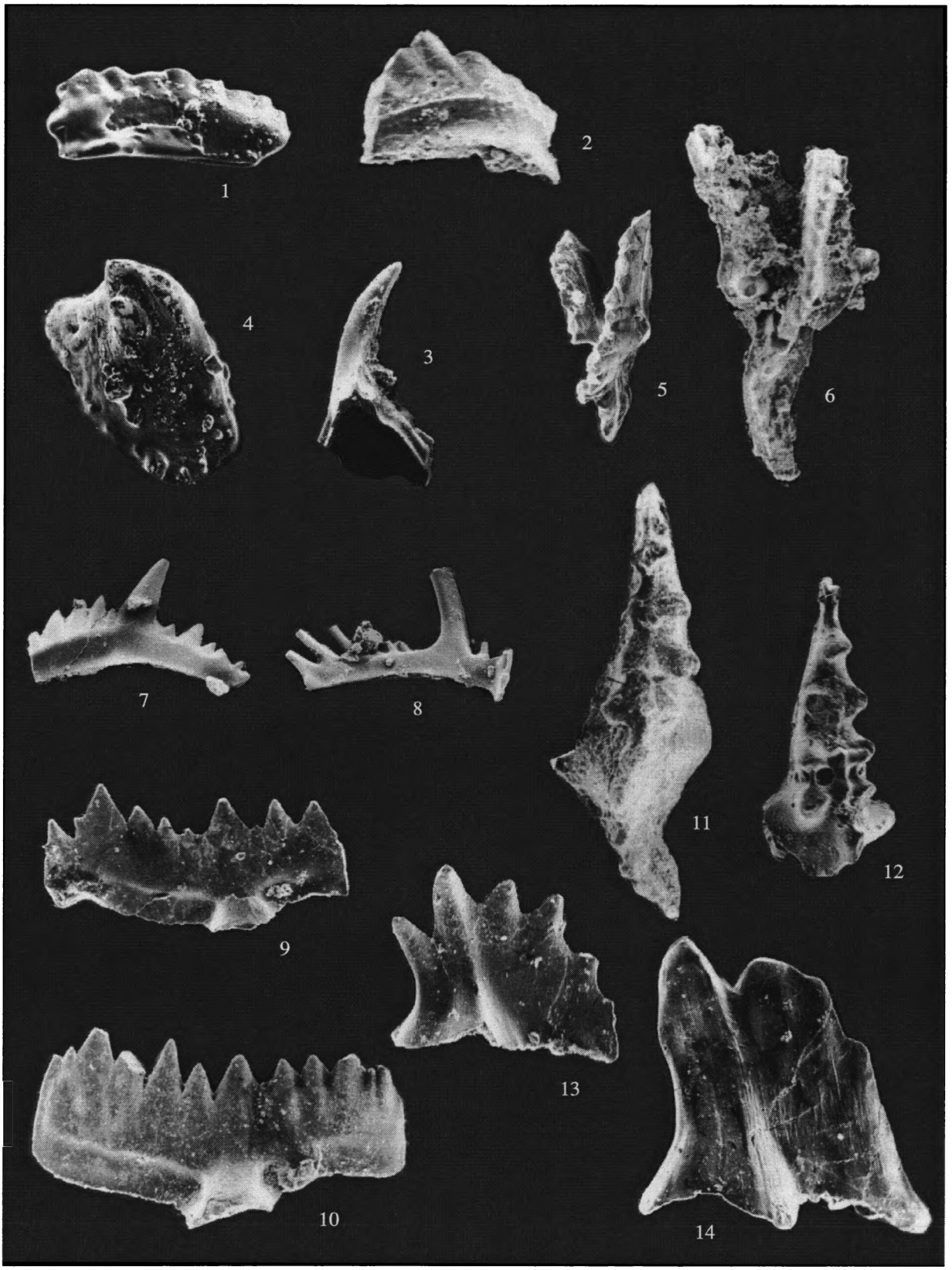
Analysis of the Fauna

The brachiopods recovered from Section 1 may be divided into provincial, regional species that inhabited a Silurian basin in the Central Asia, such as *Isorthis disjuncta* Vlad., *Leptaena kysiltchiraensis* Kulk., *Leangella scissa brevymia* Rozm., and *Eospirifer* ex gr. *tuvaensis* (Tchern.). They coexisted with cosmopolites, among them, *Dolerorthis rustica* (Sow.), and *Glassia tenella* Will. The former group is characteristic of the Kyzylchinin beds in Tuva, whose age is interpreted differently: as middle Llandoverian (Kul'kov, 1985) or late Llandoverian (Vladimirskaya, 1978, 1986; Vorozhbitov, 1992b). The cosmopolitan *Glassia tenella* Williams is typical of the middle Llandoverian in England, while the *Dolerorthis rustica* (Sow.) is common for the Wenlockian–Ludlovian of England.

The conodont assemblages recovered from samples of Section I suggest the late Llandoverian age of host rocks and provide more detailed characteristics of the *celloni* Zone. The following recovered species are typical of this zone: *Pterospathodus pennatus pennatus* (Walliser) and *P. p. procerus* (Walliser). The sequence of species in the *Pterospathodus* genus: *P. p. pennatus–P. p. procerus–P. praeamorphognathoides*, is identical to what the author discovered in the Chadan section of Tuva (Vorozhbitov, 1992b). The *P. praeamorphognathoides* indicates the presence of the uppermost part of the *P. celloni* zone in the section (Fig. 3).

Section II contains brachiopod forms *Tannuspirifer pedaschencoi* (Tchern.), characteristic of the Wenlockian Chagyr Formation in Altai and the Upper Silurian Dashtygoi–Taugantelian beds in Tuva. Other brachio-

Silurian and Devonian conodonts of Monglia: 1, *Ozarkodina* cf. *polinclinata* (Nicoll and Rexroad), Pa element lateral side ×50; Collection no. 3980/12, Gobi Altai, the Dzhissetu-Ula, 30-40 km southeast of the Shine-Dzhist salmon, 0.6 km southeast of the Shara-Chuluk-Khuduk Well; the Gobi beds, Silurian, Llandoverian; Section I, Bed 1, spec. 89-11/1. 2, *Carniodus carnulus* Walliser. Pb element, lateral side ×50; Collection no. 3980/13, the same locality, Section I, Bed 3, spec. 89-11/2a. 3, *Distomodus staurognathoides* (Walliser), Sb element, lateral side ×50; Collection no. 3980/14, the same locality; Section I, Bed 1, spec. 89-11/1. 4, *Pseudoneothodus tricornis* Drygant, upper and lateral side ×100; collection no. 3980/20, the same locality, Section I, Bed 1, spec. 89-11/1. 5, *Pterospathodus pennatus pennatus* (Walliser). Pa element, upper side ×30; Collection no. 3980/22, the same locality, Section I, Bed 1, spec. 89-11/1. 6, *Pterospathodus praeamorphognathoides* Vorozhbitov, Pa element, upper side ×50; Collection no. 3980/26, the same locality, Section I, Bed 3, spec. 89-11/2a. 7-8, *Ozarkodina excavata excavata* (Branson and Mehl): (7) Pb element, collection no. 3980/27, the same locality, (8) Sc element, lateral sides ×30; collection no. 3980/27, southern Mongolia, westernmost part of the Mandalobin Massif; the Mushugai-Khuduk Well surroundings; the Mushugai Formation, Lower Silurian, Wenlockian; Section II, Bed 1, spec. 89-26/1. 9–10, *Ozarkodina remscheidensis* (Ziegler), Pb elements, lateral sides ×30; Collection no. 3980/30,31, southeastern Mongolia, 40 km south of Barun-Urt town, 3.3 km southeast of Shavdol-Obo Mountain; Devonian, Lower Lochkovian, Sharaobin Beds; Section III, spec. 89-53/5. 11–12, *Icriodus woschmidti* cf *I.* w. *transiens* Carls and Gandle, I elements, upper sides ×35, Collection no. 3980/40,42; the same locality, Section III, spec. 89-53/5. 13–14, *Parapelekysgnathus svetlanovae* Vorozhbitov, lateral side ×30, collection nos. 3980/34,36, the same locality; Section III, spec. 89-53/5.


1
2
3
4
5
6
7
8
9
10
11
12
13
14

pods are poorly preserved and therefore identified in the open nomenclature with remarks cf and ex gr., thus being useless for the direct age determination of host rocks.

Two conodont species have been identified in Section II: *Ozarkodina excavata excavata* (Branson and Mehl) and *Pseudoneothodus beckmanni* (Bishoff and Sannemann); their distribution range extends from the Lower Silurian to the Early Devonian inclusive (Walliser, 1964; Aldridge, 1972, 1975, 1985; Klapper and Murphy, 1975; Uyeno, 1990). The third species, *Kockelella ranuliformis* (Walliser), existed from the Aeronian of the middle Llandoverian to the Sheinwoodian of the early Wenlockian. In most regions of Europe (Austria, Podolia, Lithuania), North America, Australia, Asia (Tuva), and others, *K. ranuliformis* (Walliser) commonly occur in certain parts of the interval of the *P. celloni–P. amorphognathoides–K. ranuliformis* zone of the uppermost Llandoverian–lowermost Wenlockian interval (Walliser, 1964; Barrick and Klapper, 1976; Uyeno and Barnes, 1983; Savage, 1985; Drygant, 1984; Pashkevichus, 1987; Vorozhbitov, 1992b). Only in England, this species is known to occur beginning from the middle Llandoverian (Aldridge, 1972, 1975, 1985). The close similarity between Mongolian and Tuva assemblages (Moskalenko, 1970; Vorozhbitov, 1992b) provides grounds to suggest the early Wenlockian age of the host rocks probably corresponding to the *amorphognathoides* Zone (Fig. 3).

Brachiopods from Section III are discussed in detail by Rozman (1991). I should note that brachiopods of the Sharaobin beds are grouped into: (1) Late Silurian, (2) transitional Late Silurian–Early Devonian, and (3) Early Devonian species. This section was found to contain the following conodont fauna: *Icriodus woschmidti* cf. *I. w. transiens* Carls and Gandle, *Ozarcodina remscheidensis* (Ziegler), *Parapelekysgnathus svetlanovae* Vorozhbitov, and *Panderodus* sp.

The first and second species are index forms of the *woschmidti* Zone, which is the first zone of the Lochkovian conodont scale. As for the third one, I identified it in the Lower Devonian deposits of Tuva (Vorozhbitov, 1992b). Thus, this part of the Sharaobin beds can be definitely dated as early Lochkovian in age and corresponds to the *I. woschmidti* Zone (Fig. 3).

The paucity of conodont elements in studied samples makes it impossible to draw the lower and upper boundaries of the *celloni* and *woschmidti* zones, and the next *amorphognathoides* Zone is distinguished only conventionally. Nevertheless, it is very important to assign the section intervals bearing conodonts to this or that zone of the conodont scale, as it makes it easier to date the age of host rocks and to establish their intra- and inter-regional correlation.

CONCLUSION

1. For the first time, Silurian conodonts have been recovered in Mongolia (Plate).

2. The research of conodonts from two Silurian and one Devonian section allowed us to identify conodont zones of a world-wide distribution: the late Llandoverian *celloni* Zone (Section I), the *amorphognathoides* Zone of the early Wenlockian (Section II), and the *woschmidti* Zone of the early Lochkovian (Section III).

ACKNOWLEDGMENTS

This work was supported by the International Science Foundation.

REFERENCES

Aldridge, R.J., Llandovery Conodonts from the Welsh Borderland, *Bull. Br. Mus. (Nat. Hist.), Geol.*, 1972, vol. 22, no. 2, pp. 125–231.

Aldridge, R.J., The Stratigraphic Distribution of Conodonts in the British Silurian, *J. Geol. Soc.*, 1975, vol. 131, pp. 607–618.

Aldridge, R.J., Conodonts of the Silurian System from the British Isles, *A Stratigraphical Index of Conodonts*, Higgins, A.C. and Austin, R.L., Eds., Chichester: Ellis Horwood, 1985, pp. 68–92.

Bol'shakova, L.N. and Ulitina, L.M., *Stromatoporaty i biostratigrafiya nizhnego paleozoya Mongolii* (Stromatoporoids and the Lower Paleozoic Biostratigraphy in Mongolia), Moscow: Nauka, 1985.

Drygant, D.M., *Korrelyatsiya i konodonty siluriiskikh–nizhnedevonskikh otlozhenii Volyno–Podolii* (Correlation and Conodonts of the Silurian–Lower Devonian Deposits of the Volynya–Podolia Region), Kiev: Naukova Dumka, 1984.

Klapper, G. and Murphy, M.A., Silurian–Lower Devonian Conodont Sequence in the Roberts Mountains Formation of Central Nevada, *Univ. Calif. Publ. Geol. Sci.*, 1974, vol. 111, pp. 1–62.

Kul'kov, I.P., Vladimirskaya, E.V., and Rybkina, N.L., *Brakhiopody i biostratigrafiya verkhnego ordovika i silura Tuvy* (Brachiopods and Biostratigraphy of the Upper Ordovician and Silurian of Tuva), Moscow: Nauka, 1985.

Moskalenko, T.A., Zonal Conodonts from the Silurian Section of the Elegest River (Tuva) in *Obshchie voprosy izucheniya mikrofauny Sibiri, Dal'nego Vostoka, i drugikh raionov* (General Problems of Investigating Microfauna of Siberia, Far East, and Other Areas), Moscow: Nauka, 1970, pp. 8–21.

Pashkevichyus, I.Yu. and Brazauskas, A.Z., Substantiation of the Stratigraphy of Shallow Marine and Lagoon Silurian Deposits in Eastern Lithuania, *Nauch. Tr. Vyssh. Uchebn. Zavedenii Lit. SSR, Geologiya*, 1987, no. 8, pp. 10–28.

Rozman, Kh.S., Minzhin, Ch., and Popeko, L.I. New Data on the Silurian Stratigraphy of the Sukhebator Zone (Southern Mongolia), *Izv. Ross. Akad. Nauk, Ser. Geol.*, 1991, no. 5, pp. 22–35.

Savage, N.M., Silurian (Llandovery–Wenlock) Conodonts from the Base of the Heceta Limestone, Southeastern Alaska, *Can. J. Earth Sci.*, 1985, vol. 22, no. 5, pp. 711–727.

Sytova, V.A. and Ulitina, L.M., *Rannepaleozoiskie rugozy Mongolii i Tuvy* (Early Paleozoic Rugose Corals in Mongolia and Tuva), Moscow: Nauka, 1983.

Uyeno, T.T. and Barnes, Cr.R., Conodonts of the Jupiter and Chicotte Formations (Lower Silurian), Anticosti Island, *Bull. Quebec Geol. Surv. Can.*, 1983, no. 355, pp. 1–49.

Vladimirskaya, E.V., The Biostratigraphy of the Chergak Superhorizon of Tuva, *Zap. Leningrad. Gornogo Inst.*, 1978, vol. 63, no. 2, pp. 10–22.

Vladimirskaya, E.V., *et al.*, Problems of the Silurian Paleobiography and Stratigraphy of Tuva in the Context of New Data on Brachiopods from the Chergak Formation, *Zap. Leningrad. Gornogo Inst.*, 1986, vol. 107, pp. 26–35.

Vorozhbitov, A.M., The First Lower Devonian Zonal Conodont *Icriodus woschmidti* cf. *transiens* Carls and Gandle, Found in Mongolia, *Izv. Ross. Akad. Nauk, Ser. Geol.*, 1992a, no. 1, pp. 155–156.

Vorozhbitov, A.M., Silurian–Lower Devonian Conodonts and Brachiopods in the Chadan Section, *Izv. Ross. Akad. Nauk, Ser. Geol.*, 1992b, no. 2, pp. 82–96.

Walliser, O.H., Conodonts des Silurs, *Abh. hess. geopl. Landesam. Bodenforsch.*, 1964, vol. 41.

Stratigraphy and Geological Correlation, Vol. 5, No. 4, 1997, pp. 408–412. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 4, 1997, pp. 101–105.
Original Russian Text Copyright © 1997 by Pavlyutkin.
English Translation Copyright © 1997 by MAIK Nauka/Interperiodica Publishing (Russia).

New Age Data for the Upper Cenozoic Suifun Formation in the Stratotype Region (Southern Primor'e)

B. I. Pavlyutkin

Far East Institute of Geology, Far East Division, Russian Academy of Sciences, pr. 100-letiya Vladivostoka 159, Vladivostok, 690022 Russia

Received May 15, 1995; in final form, February 19, 1996

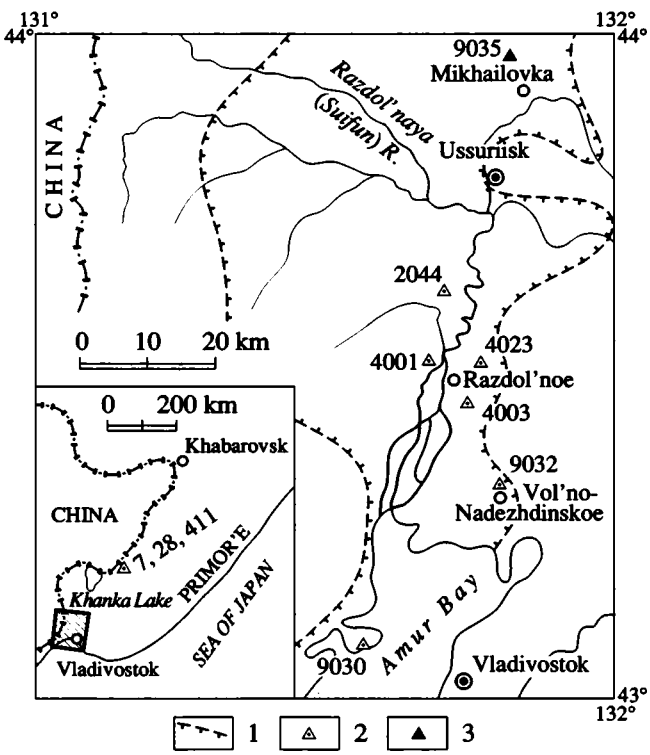
Key words: *stratigraphy, formation, leaf flora, paleocarpology, palynology, paleomagnetology*

The Suifun Formation, representing a part of the Cenozoic Erathem, is a standard of the synonymous regional horizon in the stratigraphic scheme of Upper Tertiary deposits in the southern part of the Russian Far East. The formation was originally identified by Skorokhod (1941) as a complex of weakly lithified sediments filling the Suifun erosion-tectonic basin comprising several individual depressions. It was initially thought that this unit consists of rocks of a wide lithologic spectrum such as tuff, tuffite, tuffstone, tuffaceous siltstone, sand, and pebbly gravel.

In the mid-1950s, lower tuffaceous beds of the formation were referred to a separate unit, the Ust'-Suifun Formation, whose upper age limit was accepted as corresponding to the late Miocene. The name Suifun Formation was left to the upper part of the former unit consisting of pebble beds and since that time it indicated a lesser stratigraphic range. This range was long thought to correspond to the Pliocene. However, the placing of the Ust'-Suifun Formation at the upper Miocene level was based on representative data on the leaf flora (Krishtofovich, 1946; Baikovskaya, 1974), whereas the Pliocene age of the Suifun Formation was rather a result of convention between stratigraphers than an inference substantiated by recovered fossils.

If we disregard the poor information on rare and fragmentary leaf imprints, data on flora from the Suifun Formation were thus far unavailable. Only in 1983 did I discover the flora-bearing lens of silts within pebble beds of the Suifun Formation in one well-studied section of the brown coal pit Pavlovskii-2 near the village of Mikhailovka (locality 9035, see figure), where these beds rest on the erosion surface of coal-bearing deposits. The lens yielded a rather representative collection of fossil plants consisting of 311 specimens. The collection was studied by R.S. Klimova (PGO "Primorgeologiya"), whose generalized results are presented in the table.

I believe that this list of species demonstrates a considerable difference between the studied and typical Ust'-Suifun floras. Despite the presence of some forms known from localities of the upper Miocene flora (figure), the key taxa of the new flora represent genera characteristic of present-day vegetation cover, especially of the plant groupings populating valleys. The flora in question has no analogues in Primor'e and adjacent regions. For instance, the youngest Miocene–Pliocene floras of northeastern Hokkaido, namely the Sanabushi and Rubeshibe assemblages (Tanai and Suzuki, 1965), are more thermophilic and still retain the aspect of the Turgai flora. When compared with the Miocene–Pliocene Shinjo flora of the northern Honshu described in detail by Tanai (1961), the assemblage in



Geographic scheme of studied localities: (1) boundary of the Suifun erosion-tectonic depression; (2) type sections of the Ust'-Suifun Formation; (3) type section of the Suifun Formation.

Taxonomic composition of flora from the Suifun Formation (section 9035)

Family	Plant species	Amount of specimens
Pinaceae	Pinaceae sp.	7
Ulmaceae	*Celtis* cf. *nordenskioldii* Nath.	2
Betulaceae	*Betula glandulosa* Micx. fossil.	3
Juglandaceae	*Pterocarya* cf. *protostenoptera* Tanai	2
Salicaceae	*Populus* cf. *miyataensis* Huzioka et Uemura	1
	P. cf. *kitamiana* Tanai et Suzuki	1
	P. cf. *sambonsgii* Huzioka et Suzuki	6
	Salix spp.	147
	Salix brachypoda (Trautv. et Mey) Kom. fossil.	3
	S. glauca L. fossil.	18
	S. reticulata L. fossil.	1
	Chosenia cf. *arbutifolia* (Pall.) A. Skvort. fossil.	55
Styracaceae	*Pterostyrax* cf. *rarinervis* Baik.	1
Rosaceae	*Rosa* sp.	1
	Spiraea cf. *protothunbergii* Tanai et Suzuki	17
	S. cf. *ussuriensis* Pojark. fossil.	2
Oleaceae	*Fraxinus* cf. *parvifolia* Iljinsk.	2
Caprifoliaceae	*Weigela* cf. *kamtschatica* Cheleb.	32
	Sambucus cf. *deutziafolia* Cheleb.	1
Gramineae	Gramineae sp.	3
Cyperaceae	*Carex* sp.	2
Typhaceae	*Typha* cf. *latissima* Al. Br.	2
In total: 12 families and 22 taxa representing 15 genera		311

question seems even more distinct. The younger Shiobara flora known from the monographic work of Onoe (1989) is inappropriate for comparison, because it was formed far to the south in a different botanical–geographic zone. It is also difficult to find anything slightly resembling the new flora among the Korean floras included by Huzioka (1972) in his compendium.

As Klimova stated in her preliminary conclusion, the flora under consideration is most similar in its taxonomic composition to the plant assemblage from the Erman Formation stratotype of western Kamchatka (Sinel'nikova *et al.*, 1976). It also shows a clear similarity with the Clamgulchian flora, the youngest one among the Kenaian floras from the Cook Inlet coast of Alaska (Wolfe, 1966). The last and Erman floras are located at approximately identical latitudes and at about 15° to the north of locality 9035.

Nevertheless, these similar floras with comparable taxonomic composition cannot be placed at the same stratigraphic level, because the obvious latitudinal differentiation of vegetation cover was definitely formed at the end of the late Miocene. The inapplicability of such a correlation procedure with respect to the late Cenozoic floras of comparable taxonomic composition, but developed in different latitudes, was already evident to American researchers who studied floral remains in Alaska and the northwestern United States (Wolfe *et al.*, 1966) and to Sinel'nikova and her colleagues (1976).

It is clear that the transformation of vegetation cover in the vast botanical–geographic province of Turgai, which gave rise to the East Siberian, Beringian, Kamchatka–Okhotsk, Manchurian, and other floras, was not a short event. This idea formulated first in classical works of Krishtofovich is now trivial, and consideration should currently be focused only on the rate of evolution and chronological levels of flora transformation in concrete regions of northern Asia.

These problems with respect to Primor'e remained outside the of discussion, because data on the transi-

tional Pliocene–early Quaternary floras were unavailable here. However, the impoverished flora of the Turgai type was transformed into the present-day Ussuri-Manchurian vegetation precisely in this interval. From this viewpoint, the Suifun flora is of prime significance, although the absence of analogous assemblages precludes the possibility of precisely defining its geochronological position and sends us in search of a parallel independent insight into the problem. This is quite possible, because locality 9035 is studied in many aspects.

Taking the aforesaid into account, let us first consider the data of palynological analysis obtained by N.I. Belyanina. She studied palynospectra in 19 samples of clayey silts from section 9035. The spectra can be grouped into three pollen assemblages (PA).

PA-1, samples 16–18, the lower part of the section. The dominant components of the assemblage are represented by the moderately thermophilic broad-leaved taxa *Quercus, Juglans, Ulmus*, and *Carpinus* associated with somewhat less abundant pollen of conifers *Picea* sect. *Omorica*, *P.* sect. *Eupicea*, *Pinus* s/g *Haploxylon*, and *P.* s/g *Diploxylon*. Pollen of taxa exotic for Primor'e, such as *Tsuga, Taxodium, Carya, Pterocarya, Castanea, Magnolia, Celtis*, Moraceae, *Liquidambar* ?, *Nyssa*, and *Cryptomeria*, occur here as single grains. The more notable content (up to 5%) is characteristic of the *Fagus* pollen. In addition, Sample 17 yielded rare pollen grains of *Comptonia* and *Ginkgo*.

PA-2, samples 9–15, the middle portion of the section including the flora-bearing bed. Abundance of broad-leaved pollen decreases here, whereas birch pollen, including representatives of frutescent forms, and pollen of gymnosperms (pines and fir) is more abundant. Specimens of some exotic taxa listed above are still present in this assemblage, though sporadically.

PA-3, samples 1–8, the upper part of the section. Palynospectra display the further depletion in the broad-leaved pollen and the nearly complete absence of exotic taxa. They also show a higher abundance of arboreal birch forms, and mark the appearance level of alder pollen.

The distribution and taxonomy of pollen species in these spectra suggest that the boundary separating PA-1 and PA-2 is the most significant in the section. It marks the time of the principal event responsible for the disappearance of *Taxodium* species and some other relatively thermophilic elements (*Comptonia, Nyssa*, and others).

The age of palynofloras in question is detectable on the basis of correlation with taxonomically similar floras from adjacent regions. In Primor'e, floras of comparable composition are typical of lower beds of the sedimentary complex filling the ancient incisions in the Khanka Lake depression (Korotkii and Pavlyutkin, 1984). The beds enclosing them show reversed magnetic polarity and are interpreted as corresponding to the Matuyama Chron.

Palynospectra of PA-2 and PA-3 are also comparable with palynofloras from the members IV and V of the Maruyama Formation of Sakhalin. Aleksandrova (1982) referred these members with reversed magnetic polarity to the late Pliocene–Eopleistocene interval. In the Amur River region, pollen assemblages compatible in composition with palynospectra from the upper portion of section 9035 are known from the Belogorsk Formation dated back to the Early Quaternary (Makhova, 1978). In addition, PA-3 is comparable with palynospectra from lower beds of the coarse-grained Eopleistocene (Early Quaternary) deposits of the Priamurskaya Formation of the Evoron–Chukchagir depression (Vikhlyantsev and Morozova, 1965).

Further to the south, in Japan, the well-studied palynoflora of the Osaka Group is of the transitional Pliocene–Quaternary age. When considering this flora, it is important to focus attention on the Taxodiaceae, whose pollen was used by Japanese scientists as a basis to discriminate the lower *Metasequoia* and upper *Fagus* palynozones. In the type section, the boundary separating these palynozones is below the Matuyama–Brunhes reversal, but above the Jaramillo Subchron (Suzuki and Nasu, 1983). However, this region is far to the south from our locality, and the Osaka floras are hardly applicable for correlation.

In northeastern Honshu (the Aizu Basin), *Metasequoia* disappears from palynospectra somewhat earlier, precisely in the Olduvai Subcron (1.8 Ma ago), although its pollen may occasionally occur up to the lower boundary of the Jaramillo Polarity Subzone (Suzuki and Manabe, 1987). In the coastal zone of the Ishikari basin of Hokkaido, which is almost at the latitude of section 9035, the same event is confined to the boundary between the Uranosawa and Shimonopporo formations coinciding with the Olduvai Subchron (Kitagawa *et al.*, 1988).

In Hebei Sheng of northeastern China (40° N), an analogous change in palynofloras is recorded inside the Nihewan Formation (Zhou *et al.*, 1983), whose beds with reversed polarity are attributed to the Matuyama Cronozone (Li and Wang, 1982). According to An (1987), the respective boundary also corresponding to the Olduvai Subchron (Li and Wang, 1982) marks the level from where the ancient mammalian fauna shows its enrichment in Quaternary forms.

Correlating thus palynofloras from different regions, we can conclude the following. As the climate in southern Primor'e is somewhat cooler than in Hokkaido and northern Hebei Sheng, it is reasonable to suggest that, in the first region, changes in palynoflora composition took place no later than 1.8 Ma. Accordingly, upper floras in section 9035 seem to be of the Eopleistocene age, whereas the lower member with PA-1 is likely displaced here in the Pliocene.

In turning back now to the leaf flora 9035 of this locality (table), one should recall that it is lacking *Metasequoia, Taxodium*, and *Glyptostrobus*, the usual

components of the Turgai leaf floras, including their young impoverished assemblages. It would be incorrect to assume here an influence of local factors, as this could contradict the carpological data supplementing analytical results on the leaf flora and pollen assemblages. In addition to four beds in section 9035, carpolites were collected in some points of a stripping trench, which exposed pebble beds of the Suifun Formation along a distance of several kilometers. Despite a high abundance of coniferous carpolites, none of the samples yielded species of Taxodiaceae, and this may indicate them to have been extremely rare in the vegetation cover of southern Primor'e during the accumulation of the Suifun Formation.

The carpogeneous floras of the region are very diverse. According to P.I. Dorofeev, they include 126 taxa of arboreal, frutescent, and herbaceous plants. Some of the taxa (over 10%) are either extinct or growing in the warmer climatic zones. These data allowed Dorofeev to suggest the Eopleistocene age of carpolites from the Suifun Formation, including the section 9035.

To refine the chronological level of the flora in question, I also used paleomagnetic data. Samples for measurements were collected from twenty levels, three per each. Measurements and interpretation were performed at the Laboratory of Paleomagnetology, Northeast Research Institute, Far East Scientific Center, Academy of Sciences of the USSR (Magadan). As T.I. Lin'kova concluded, all the samples have reversed polarity. This fact additionally proves that floras from section 9035 apparently are of the Eopleistocene age, and only lower beds of the enclosing Suifun Formation can be displaced down in the Pliocene interval.

In addition to paleobotanical and paleomagnetic data, geological relations with underlying rocks also do not permit an older age to be assigned to the Suifun Formation. In marginal zones of the Khanka Lake depression (wells 7, 28, and 411; see figure), the aforementioned pebble beds with carpolites and pollen assemblages resembling those from section 9035 rest on red clays. Near the last locality, the red gravely clays crown the pre-Quaternary interval of the deposits underlying the pebble beds of the Suifun Formation, which is thus older than the red beds in both cases. In Primor'e, beds of the last type, which enclose here gravel, pebbles, and lenses of sand, are barren of paleontological remains. However, analogous strata in northeastern China, the Transbaikal region, and Mongolia yielded molluscan and mammalian fauna of the late Pliocene age.

In conclusion, I would like to mention one more point concerning the leaf flora considered here. In my opinion, it cannot be derived from the Ust'-Suifun flora, and therefore, both floras are not neighbors in the paleosuccession line. A lacuna between them can correspond first of all to the flora of the Botchi type, whose upper age limit is defined by Akhmet'ev (1973) as the lower half of the Pliocene. In southern Primor'e, floras of this type are still unknown, although they may be present in the tuffaceous silts, tuffstones, and opokas intercalated with basaltic lava flows. In the general geological section of Tertiary deposits in Primor'e, this rock sequence is transitional between the Ust'-Suifun and Suifun formations.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research, project no. 95-15309a.

Reviewer M.A. Akhmet'ev

REFERENCES

Akhmet'ev, M.A., *Miotsenovaya flora Sikhote-Alinya (r. Botchi)* (Miocene Flora of the Sikhote Alin, Botchi River), Moscow: Nauka, 1973.

Aleksandrova, A.N., *Pleistotsen Sakhalina* (The Pleistocene Series of Sakhalin), Moscow: Nauka, 1982.

An Zhisheng, Study on Lower Boundary of Quaternary in North China—an Important Climato-Geological Event in Early Matuyama Chron, *Marine Geol. Quatern. Geol.*, 1987, vol. 5, no. 4, pp. 95–103.

Baikovskaya, T.N., *Verkhnemiotsenovaya flora Yuzhnogo Primor'ya* (Late Miocene Flora of the Southern Primor'e), Leningrad: Nauka, 1974.

Huzioka, K., The Tertiary Floras of Korea, *J. Mining College Akita Univ., Ser. A*, 1972, vol. 5, no. 1, pp. 1–83.

Kitagawa, Y., Igarashi, Y., Yoshida, M., and Koshimizu, S., Pleistocene Stratigraphy in the Ishikari Lowland, Hokkaido, Japan., *Mem. Geol. Soc. Jpn.*, 1988, no. 30, pp. 13–23.

Korotkii, A.M. and Pavlyutkin, B.I., The Pliocene–Quaternary Boundary in the Continent–Ocean Transition Zone (Southern Area of the Far East), in *Stratigrafiya pogranichnykh otlozhenii neogena i antropogena Sibiri* (Stratigraphy of the Neogene–Anthropogene Boundary Deposits in Siberia), Novosibirsk: Inst. Geol. Geofiz. Sib. Otd. Akad. Nauk SSSR, 1984, pp. 85–100.

Krishtofovich, A.N., Miocene Plants from the Suifun Formation of the Ussuriisk Region, *Botan. Zh.*, 1946, no. 4, pp. 1–34.

Li H. and Wang J., Magnetostratigraphic Study of Several Typical Geological Sections in North China, in *Quaternary Geology and Environment of China.*, China Oceans Press, 1982, pp. 33–38.

Makhova, Yu.V., Paleobotanical Characteristics of the Belogorsk Formation in the Amur–Zeya Depression, *Byull. Kom. Izuch. Chetvertichn. Perioda, Akad. Nauk SSSR*, 1978, no. 48, pp. 170–179.

Onoe, T., Palaeoenvironmental Analysis Based on the Shiobara Volcanic Basin, Central Japan, *Mem. Geol. Surv. Jpn.*, 1989, no. 269.

Sinel'nikova, V.N., Fot'yanova, L.I., Chelebaeva, A.I., *et al.*, *Mio-pliotsen Zapadnoi Kamchatki* (Miocene–Pliocene of Western Kamchatka), Moscow: Nauka, 1976.

Skorokhod, B.Z., *Osnovnye cherty geologicheskogo stroeniya yuzhnoi chasti Sovetskogo Dal'nego Vostoka* (Main Features of Geological Structure in the Southern Part of the Soviet Far East), Vladivostok: Primorskoe Geograf. O–vo., 1941.

Suzuki, K. and Manabe, K., Pliocene–Pleistocene Stratigraphy and Chronology in the Aizu Basin, Northeast Honshu, Japan, *Proc. First Int. Colloquium on Quaternary Stratigraphy of Asia and Pacific Area,* Osaka, 1987, pp. 24–31.

Suzuki, K. and Nasu, T., Plant Biostratigraphy of the Plio–Pleistocene Series in Japan, *Mem. Geol. Soc. Japan,* 1983, no. 30, pp. 169–180.

Tanai, T., Neogene Floral Change in Jpn., *J. Faculty Sci. Hokkaido Univ., Ser. 4,* 1961, vol. XI, no. 2, pp. 119–398.

Tanai, T. and Suzuki, N., Late Tertiary Floras from Northeast Hokkaido, Japan, *Spec. Pap. Palaeontol. Soc. Jpn.,* 1965, no. 10, part 2, pp. 51–117.

Vikhlyantsev, V.V. and Morozova, V.F., New Data on Cenozoic Stratigraphy in the Evoron–Chukchagir Depression, in *Sbornik statei po geologii i gidrogeologii* (Papers on Geology and Hydrogeology), Moscow: Nedra, 1965, no. 5, pp. 24–32.

Wolfe, J.A., Tertiary Plants from the Cook Inlet Region, Alaska, *U.S. Geol. Surv. Prof. Pap.*, 1966, no. 398-B.

Wolfe, J.A., Hopkins, D.M., and Leopold, E.B., Tertiary Stratigraphy and Palaeobotany of the Cook Inlet Region, Alaska, *U.S. Geol. Surv. Prof. Pap.*, 1966, no. 398-A.

Zhou K., Liang X., Yan F., and Ye Y., Some Remarks on the Nangou Cold Period Based on the Analysis of the Pollen from the Nihewan Stratum, *Sci. Geol. Sinica*, 1983, no. 1, pp. 82–92.

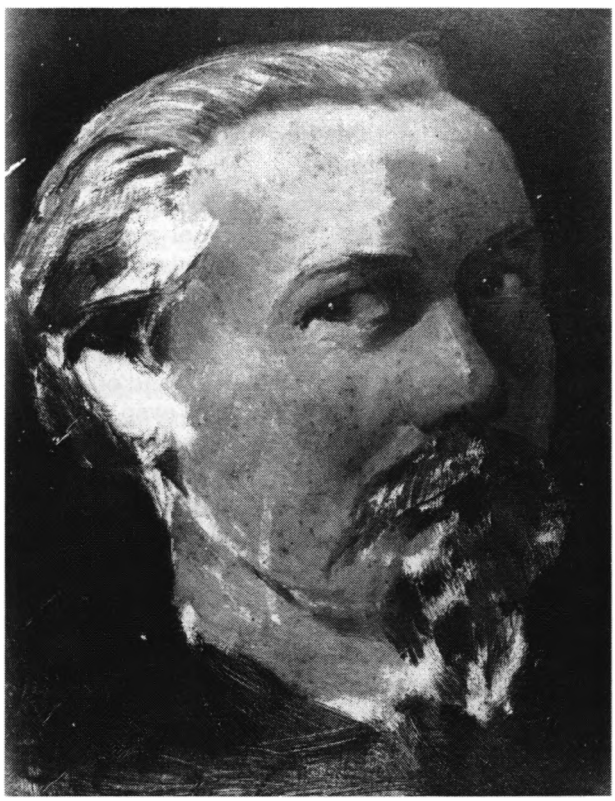
Stratigraphy and Geological Correlation, Vol. 5, No. 4, 1997, pp. 413–417. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 4, 1997, pp. 106–112.
Original Russian Text Copyright © 1997 by Romanovskii.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

The Contribution of N. A. Golovkinskii to Theoretical Stratigraphy (1834–1897)

S. I. Romanovskii

All-Russian Research Institute of Geology (VSEGEI), Srednii pr. 74, St. Petersburg, 199026 Russia

Received February 27, 1996



June 21, 1997, marks 100 years since the death of the outstanding Russian scientist Nikolai Alekseevich Golovkinskii, a unique and most prominent figure in the geology of the nineteenth century, who had a rare gift to "see" the most hidden sides of the phenomena he explored. Even V.I. Vernadskii, in his autobiography, admitted that Golovkinskii's influence on him was most profound: "As compared with Dokuchaev and Inostrantsev, Golovkinskii seemed to be the more broad-minded researcher of the European type" (*Stranitsy avtobiografii...*, 1981, p. 179), though Vernadskii had but a nodding acquaintance with him, while Dokuchaev and Inostrantsev were his immediate teachers at Petersburg University. Due to unremitting toil and the depth of his learning Golovkinskii achieved such great and encouraging results, that numerous researchers widely use his theoretical heritage even today.

In fact, lithologists, stratigraphers, and tectonists know Golovkinskii as the author of the oscillatory-migratory bedding theory (the term proposed by N.B. Vassoevich), which served as a basis of the facies law now widely recognized (it will be referred to again). It was Golovkinskii who introduced the conceptions of facies (1865) and differentiated the complex fluctuating movements of the Earth's crust (1865). Geomorphologists know Golovkinskii as the author of the stratifcation-tectonic hypothesis of river valley asymmetry, who introduced "the formation rules" of river terraces. He is known by hydrogeologists as the author of the condensation hypothesis of ground water formation who scientifically substantiated strategies to be used in the exploration of deep artesian waters. He was a pioneer in proposing to set up "artesian observatories," i.e., permanent hydrogeological stations, and himself organized the first such station in the town of Saki in the Crimea.

And, finally, stratigraphers might remember that one of most "inconvenient" rules of theoretical stratigraphy, the rule of time diachronism of stratigraphic horizons, is associated with Golovkinskii's theory of sedimentary bedding. Below, I shall focus on this problem.

However, first, I should give a brief biography of Golovkinskii, as his life was as fascinating and unique as the scinetific heritage that he left for us (Romanovskii, 1979).

In 1851, at seventeen years of age, he entered the Medical Faculty of the Kazan University as an auditor. Anatomy was one of his favorite subjects. However, he later became increasingly interested in botany. His studies were interrupted by the Crimean War. The fledgeling scientist had to calm his turbulent nature in battles. As a member of the Uhlan regiment, he participated in that heroic (though disgraceful for Russia) war. Following the restoration of peace, he continued his studies at Kazan University, now at the Faculty of Physics and Mathematics. Golovkinskii had not lost his interest in botany but, influenced by such a prominent scientist as A.M. Butlerov, he focussed his attention on chemistry. At that time, he published his first scientific

papers, and his first success came to him. Without a day of rest Golovkinskii went on with his scientific research. He tried to determine the main source for his professional career. Along with chemistry, he studied mineralogy and geology. Having completed his studies at the university and even after gaining his candidate degree in natural sciences (1861), Golovkinskii had not yet chosen his path in science. In Germany, where he was sent to be trained in order to obtain the rank of professor, he left chemistry and decided to choose between geology and mineralogy. And upon his return to Russia in 1864, he had decided in favor of geology.

Then followed years of teaching and fighting for the democratic liberties provided by the 1863 University Regulations. Golovkinskii was in the center of this fight. The atmosphere got frenzied when in 1871 the students' favorite professor of anatomy, P.F. Lesgaft, was dismissed from his position. His friends tried to defend him, but all was in vain. Following these events, seven of the best professors of Kazan University, with Golovkinskii at the head, demonstratively retired from the University.

Golovkinskii moved to Odessa. His strong beliefs along with his good will, kindness, and his distinguished influence in science earned him the respect and fascination of colleagues of Novorossiisk (now Odessa) University, such as I.I. Mechnikov, I.M. Sechenov, A.O. Kovalevskii, N.A. Umov, and other prominent Russian scinetists. Five years later, Golovkinskii was elected rector of Novorossiisk University. However, his term as a rector (1877–1881) was a most difficult period for him, left "a dismal feeling in his heart" (A.E. Lagorio), and, moreover, adversely affected his health. Golovkinskii felt fully exhausted. He left Odessa with a diseased heart, filled with great apprehension. In 1886, he moved to his dacha *Kastel'*, situated in the Crimea near Alushta, where he lived for the rest of his life, serving as a hydrologist for the Tavricheskoe zemstvo. Such was Golovkinskii's odyssey.

It is noteworthy that stratigraphic problems have never been particular topics of his interest. And still, stratigraphy is the field of earth science to which he has contributed the most. "The conception of diachronism of stratigraphic horizons," or merely "Golovkinskii's principle," is one of the key principles among diverse stratigraphic conceptions. It is inferred from the migrating bedding theory created by Golovkinskii. The theory is outlined in his monograph *Permian Sequence in the Central Part of the Kama–Volga Basin* (1868). In 1868, Golovkinskii submitted the monograph to the Scientific Board of Kazan University as his doctorate. In 1869, the Mineralogical Society of St. Petersburg published it in Volume I of *Materials on Geology in Russia.*

Incidentally, after more than 100 years, Golovkinskii's scheme of bedding has not appreciably altered. Moreover, it is widely recognized by geologists, and has been analyzed in detail in my monographs (Romanovskii, 1979, 1985, 1988a) and in many publications by other geologists: N.B. Vassoevich, I.A. Vyltsan, B.P. Vysotskii, G.A.Dmitriev, I.P. Druzhinin, G.F. Krasheninnikov, G.P. Leonov, N.S. Morozov, G.I. Sokratov, Yu.Ya. Solov'ev, and others. Therefore, I shall not dwell on this point now and shall confine myself to mentioning the main results that obviously follow from it.

1. A complete cycle of fluctuating movements corresponds to a full deposition cycle in the section, the whole "geological lens" of Golovkinskii.

2. Geological bodies extending subparallel to the shore line of the basin should be regarded as beds.

3. Since each bed is not formed "abruptly" but through progressive displacement of the shore line, its age along the strike varies.

4. The bed is interpreted as a non-coeval and lithologically homogeneous unit.

Golovkinskii has not only established that tectonic factors control the migration of facial zones, he also suggested that such understanding leads us to interpret the mechanism of bed formation differently. It comes as no surprise that Golovkinskii's scheme was not understood and not accepted by many of his contemporaries, among them Inostrantsev, Kovalevskii, and others. The scheme seemed so extraordinary that even Golovkinskii himself, realizing that it was beyond the scope of traditional conceptions, called his major conclusion on the diachronism of beds "paradoxical."

Golovkinskii (1868, p. 125) wrote, "let us assume that we are analyzing a formation composed of sandstone, marl, and limestone beds, overlying one another .... It may logically be suggested that they had precipitated one after the other in successive epochs; however, if such stratification makes up only the lower part of the geological lens, which remained after erosion, ... then such interpretation can be applied only to *a very restricted area.* (italics mine)[1]. Further follows his famous conclusion: "... it enables us to propose a thesis, evidently paradoxical, that *"the generally accepted idea that beds successively overlying one another are formed in the same succession is not correct."* (italics Golovkinskii's) (*Ibid.*, p. 125).

Virtually, Golovkinskii's thesis is not at all paradoxical (Romanovskii, 1979). To understand this, we should compare the scope of diachronism of an isolated bed with the time difference between the formation of adjacent beds because, as soon as we refer to Golovkinskii's theory, we note its apparent contradiction to Stenon's principle. Where does this contradiction lie? Golovkinskii believed that when the "lowermost layer" was under formation, upper layers already *existed*, though not in the vertical succession but arranged later-

[1] This is a very important idea, giving the essence of Golovkinskii's theory: diachronism of beds is meaningful only in whole basins or their extensive parts; naturally in an isolated section or closely spaced sections, diachronism is impossible to identify.

ally. The stratification was formed by the superposition of facial zones, but according to the scheme, a bed is diachronous in its different parts, thus suggesting the conclusion, as if contradicting Stenon's principle, that upper beds might be older than lower ones.

I have also established (Romanovskii, 1979) that, although Golovkinskii's principle suggests that each bed is diachronous, this time difference is always less than that required to evaluate the successive stratigraphic bedding. Therefore, any overlying bed of the migration type is always younger than the underlying one; that is, the lateral age gradient is commonly lower than the vertical (stratigraphic) gradient, and Stenon's principle does not contradict Golovkinskii's theory of bed formation.

A.I. Zhamoida (1980, p. 42) reasonably suggested that correlation of stratigraphic and lithological units "is a complicated and, at best, poorly explored problem," that a lithological sheetlike body is separated from adjacent lithological bodies by "similar boundaries," and that those boundaries reflect changes in the sedimentation conditions in "each given area." All this means that such a bedding is of the asynchronous migration type, for which Golovkinskii created his scheme. It is also evident that each bed of the formation or any other local unit is "diachronous," while the age changes from one isochronous "step" to another. However, it is impossible "to percieve" the age change within one bed, as the lateral gradient of diachronism is very low. Incidentally, when we measure the age of a formation, especially in widely separated sections, the age change can be detected by detailed biostratigraphic methods. It is very difficult to explain Golovkinskii's scheme in terms of practical stratigraphy because, analyzing specific sections of the Kama–Volga Basin, Golovkinskii expressed himself as a theorist–lithologist, but not as a stratigrapher; he investigated diachronism of a bed along the strike, treating the bed as a lithological unit. When the method of boundary diachronism, inferred from his scheme, became used by stratigraphers, they had to deal with the "summarized" lithological beds, that is with the unit containing beds of a similar formation type and, consequently, they provided practical confirmation of Golovkinskii's theoretical conclusions. It is clear that diachronism of boundaries of local units is of real significance for stratigraphers, and, therefore, V.A. Krasilov's comment (1977, p. 188) that "examples of diachronism are related to a group of beds rather than to a single one," is quite correct.

Considering Golovkinskii's "paradoxical" thesis, with due regard to the above explanations, we may easily see its compatibility with *the basic facies law.* However, if beds were formed not successively (one after another), but by superposition of contiguous facial zones, as reported by Golovkinskii, the law of facies migration naturally follows from here: *the vertical rock succession in a section (within one sedimentation cycle) should repeat the lateral arrangement of facial zones across the strike of the shore line of the sedimentation basin.*

It is noteworthy that the law of facies migration received this status not only because it was not in contradiction with observations (many other genetic schemes were also not in contradiction with observations), but because it corresponded to the formation theory of migration bedding, meticulously elaborated by Golovkinskii. In principle, such a theory could appear unverifiable (for example, how to check whether beds are formed by even or spasmodic oscillations of the earth crust). As for Golovkinskii's theory, it apparently gave rise to a new phenomenon, unknown earlier by geologists: *diachronism of geological units*, petrographic, stratigraphic, and paleontological (these terms were also introduced by Golovkinskii). It is this part of the theory that was not understood by many geologists, Golovkinskii's contemporaries, and this was the reason why the theory was ignored for many years. When specialists took it up again, it was considered one of the possible theories of bedding origin, whereas the law of facies migration was unjustifiably connected with Inostrantsev (it was he who formulated the law, though it did not follow from his scheme of bedding origin) and with I. Valter, who discovered it 25 years later (Romanovskii, 1988b).

Meanwhile, stratigraphers have demonstrated that diachronism of local stratigraphic units was not Golovkinskii's fancy, but a real fact that should not be ignored in stratigraphic correlations.

The essence of diachronism of local stratigraphic units is that their age variation is dependent on a single major factor or mechanism controlling the accumulation of beds. Incidentally, this mechanism depends not upon processes occurring in the basin, but on external factors relative to the sedimentation system, which cause changes of the system configurations with time. This concerns the kinematics of diachronism.

Practically, only stratigraphers can detect an age increment as it is insignificant within one isolated bed; however, within a formation this parameter is augmented and can be estimated by methods of detailed biostratigraphy. Stratigraphers' reasoning is simple and correct: if there is no reliable evidence indicating that units are non-coeval, then they are concurrent (S.V. Meien, V.A. Zubakov, and others). True, this is a theorist's interpretation. Empiric stratigraphers consider diachronous boundaries as an interfering factor that makes the correlation of sections and local stratigraphic schemes more complicated. Therefore, many stratigraphers, in defiance of the obvious, are still trying to confirm the thesis that boundaries of formations are always isochronous, irrespective of their composition and the formation mechanism of constituent deposits.

Nevertheless, stratigraphic research made evident that the boundaries of formations with *bedding of migration type* are diachronous, and the larger the

diachronism, the longer is the traceable length of the boundary. In areas where stratigraphy is known in detail, and accepted boundaries of local subdivisions are important for prospecting and exploration work (as, for example, in West Siberia), diachronous formations are no longer an exception. Quite the contrary, the isochronism of boundaries is even to be confirmed (Trushkova, 1980).

Detailed stratigraphic exploration of the sedimentary cover of the West Siberian plate provided many examples of diachronous stratigraphic horizons. They are common in Neocomian formations (S.P. Bulynnikova, A.V. Gol'bert, F.G. Gurari, I.G. Klimova, V.A. Martynov, L.Ya. Trushkova, and others), as is shown biostratigraphically by detailed age correlation of Neocomian ammonites. The age in the lateral direction notably increases by 2–3 stages. Diachronism is also recorded in the so-called salt-pan horizon. It resulted from the gradually evolving regression of the Late Jurassic–Neocomian marine basin of the West Siberian plate. From south (Petropavlovsk) to north (Tobol'sk), the age of this horizon changes from the terminal early Valanginian to the terminal early Hauterivian or, even, to the late Hauterivian. Therefore, the general regression of the Neocomian Basin started in Western Siberia at the end of the early Valanginian.

Trushkova's approach (1980) to the problem of diachronous boundaries is very reasonable. She believes that the position of all stratigraphic taxa within the West Siberian plate is controlled by Golovkinskii's principle, and the objective of stratigraphers is to precisely estimate the gradient of the diachronism, rather than to debate the usability of this principle. Her analysis indicated that the upper age of the Tatarian Formation rejuvenates from southeast (Pyl-Karamin megaswell) to northwest (Lar-Egan swell). Incidentally, in terms of the International Stratigraphic Scale, the diachronous interval corresponds in this case to the entire Valanginian, thus being equal to 8–10 Ma.

However, despite numerous examples confirming the benefits of Golovkinskii's principle, there are geologists who, ignoring its reliable scientific background, do not want to accept it and offer vigorous arguments to make it an exception from the general rule.

Yet, the inverse case is most likely correct, and isochronous boundaries of formations with bedding of the migratory type appear to be an exception, in contrast to diachronous boundaries, though it is not yet proved due to the lack of methods allowing detection of the gradient of diachronism. The mechanism of bedding which "inevitably" leads to diachronism of a bed along the strike is the basis of the principle named after Golovkinskii. Following this principle, we should provide convincing arguments in favor of isochronous (not diachronous) surfaces, separating the subdivisions of local stratigraphic schemes. "A principle should be a postulate and not a thing to be proved," Trushkova remarked (1980, p. 66).

It would be interesting and significant to clarify the very mechanism of diachronism. The sedimentological explanation of Golovkinskii's theory suggests that the gradient of diachronism (disregarding other factors) is a function of the strike angle of the section relative to the ancient shore line of the basin. If the section is parallel to the shore line, then the gradient of diachronism is zero; the gradient is the highest if the section is perpendicular to the ancient shore line.

I should note another important consequence of Golovkinskii's theory, which provides sedimentological explanation of the mechanism responsible for diachronism of stratigraphic boundaries. As the gradient of diachronism may be established only in a bedding of the migration type, it appears only when the shore line displacement inside the continent is a sufficiently long phenomenon, i.e., when transgression evolves "slowly" without any appreciable reconstructions of the basin facial zones. As a result, rock complexes of similar lithology (formations or rock associations) yield different paleontological dating in widely separated sections. It is vital that the sedimentation rate should be commensurable with the rate of transgression development; in this case, physical and geological conditions in the basin would be stable for an extended period of time.

The pure sedimentological nature of the mechanism responsible for diachronism can be understood using the theory of plate tectonics, as for kinematic processes it makes no difference what "forces" bring about the spatial displacement of accumulation zones of lithologically identical sediments. It does not matter whether it is a process of transgression (Golovkinskii's classical scheme), or a lateral migration of a plate from the divergence zone of the mid-ocean ridge (plate tectonic interpretation of the process). According to both interpretations, the age of lithologically similar assemblages will change in the direction of the substrate displacement: during transgression it will become progressivly younger, while during regression it will become increasingly older.

Oceanic drilling data have confirmed the conclusion following from the theory of lithosphere plates: the deposits overlying the basaltic ocean floor are increasingly older the farther away they occur from the mid-ocean ridge. Recent sediments are in the ridge areas; closer to subduction zones they are progressively older. If we take the scheme of a spreading conveyer, the mechanism of this phenomenon seems quite clear: the mid-ocean ridges are zones of continuous crust accretion and separation of plates on both sides of the ridge. The plate movements toward the subduction zones lasted 150–200 Ma and were accompanied by sedimentary cover thickening. The "particle after particle" sedimentation secured the age differentiation of sedimentary layers accumulated on the oceanic floor, and simultaneous plate movements toward the Benioff zones

resulted in the diachronism of these "layers" (in the stratigraphic meaning of the term).

It is clear that if the basaltic layer of the ocean floor progressively "changes" with an increase of the distance from the mid-ocean ridge, the age of the overlying sediments will inevitably be "diachronous". The sedimentary succession on the horizontal mobile substrate is to be interpretated in a different way. In the common terminology, the oceanic sedimentary sequence always displays the transgressive trend, in other words, the most shallow (if we may say that about sedimentation at the foot of the mid-ocean ridges, that is, at the depth of more than 2000 m) sedimentary formations are always confined to the basement of the section, and farther away from the zone of plate divergence, the overlying sediments gradually become of more deep-water origin. Thus, the deep-sea drilling holes, which reached the basaltic basement, revealed that the basaltic basement is usually covered with pelagic carbonate sediments accumulated above the carbonate compensation level and siliceous deposits or deep-water red clays usually overlie carbonates (Zonenshain and Savostin, 1979).

Areas occupied by the basaltic floor of the oceans of a paticular age were found to diminish linearly as their age increased (Berger and Winterer, 1974). Young crust, the age of which does not exceed 20 Ma, occupies about 20% of the floor area, whereas the floor area where the crust is 140 Ma in age makes up less than 5%. Oceanic areas occupied by pelagic sediments of a particular age have the same proportions.

Therefore, the spreading theory and related paleosedimentological problems require an essentially new approach to analyze the stratification of sedimentary strata, since in addition to oscilatory movements of the floor (vertically oriented movement vector), it is necessary to take account of the substrate lateral displacement (horizontally oriented movement vector). The stratification, recorded in the sections, is a result of the summing of two vectors; it always includes a certain age gradient.

Zhamoida discussed the same problems, but from another point of view (1980, pp. 42-43): "a certain resultant level between elements of boundaries of two types," stratigraphic and lateral, is regarded by him as a "transgressive boundary" of the whole stratigraphic unit. It is clear that when the unit is divided into increasingly smaller fractions, "the value of *diachronism* of this resultant level is also reduced. The smaller the study area, the lower the diachronism degree of the boundaries of the formation and other local stratigraphic units, and in the smallest areas it may be ignored." These interpretations are fully compatible with the ideas of Golovkinskii cited here from his famous monograph (1868), which is now widely recognized.

Returning to the spreading theory, one can see that it may lead to new insights into the sedimentological background of stratigraphy. First of all, this concerns the proper argumentation of stratigraphic diachronism, to make Golovkinskii's principle efficient both in theoretical and practical stratigraphy.

ACKNOWLEDGMENTS

I am thankful to A.I. Zhamoida for reviewing the manuscript of this article and for his valuable comments.

REFERENCES

Berger, W.H. and Winterer, E.L., Plate Stratigraphy and the Fluctuating Carbonate Line, in *Pelagic Sediments: Land and Sea*, Oxford, 1974, pp. 11–48.

Golovkinskii, N.A., *O permskoi formatsii v tsentral'noi chasti Kamsko-Volzhskogo basseina* (Permian Formation in the Central Part of the Volga-Kama Basin), St. Petersburg, 1868.

Krasilov, V.A., *Evolyutsiya i biostratigrafiya* (Evolution and Biostratigraphy), Moscow: Nauka, 1977.

Romanovskii, S.I., *Nikolai Alekseevich Golovkinskii (1834–1897)* (Nikolai Alekseevich Golovkinskii: 1834–1897), Leningrad: Nauka, 1979.

Romanovskii, S.I., *Dinamicheskie rezhimy osadkonakopleniya. Tsiklogenez* (Dynamic Regimes of Sedimentation: Cyclogenesis), Leningrad: Nedra, 1985.

Romanovskii, S.I., *Fizicheskaya sedimentologiya* (Physical Sedimentology), Leningrad: Nedra, 1988a.

Romanovskii, S.I., History of the Discovery and Authorship of the Main Facies Law, *Voprosy istorii estestvoznaniya i tekhniki*, 1988b, no. 4, pp. 87–94.

Stranitsy avtobiografii V.I. Vernadskogo (Selected Pages from V.I. Vernadskii's Autobiography), Moscow: Nauka, 1981.

Trushkova, L.Ya., Stratigraphic Principles and Regional Correlation Schemes (Exemplified by the Mesozoic of the West Siberian Plate), *Tr. Sib. Nauchno–Issled. Inst. Geol. Geoph. Miner. Res.*, 1980, vol. 282, pp. 65–78.

Zhamoida, A.I., The Essence and Relationship between Main Stratigraphic Units, in *Stratigraficheskaya klassifikatsiya. Materialy k probleme* (Stratigraphic Classification: Materials on the Problem), Leningrad: Nauka, 1980, pp. 32–63.

Zonenshain, L.P. and Savostin, L.A., *Vvedenie v geodinamiku* (Introduction to Geodynamics), Moscow: Nedra, 1979.

Translated and Published by **МАИК Наука/Interperiodica Publishing**
Distributed Worldwide by **Plenum/Consultants Bureau**

Lithology and Mineral Resources

Editor-in-Chief
Vladimir N. Kholodov
Member of the Russian Academy of Sciences, Doctor of Geology and Mineralogy

SCOPE

Lithology and Mineral Resources (Litologiya i Poleznye Iskopaemye) reviews a wide range of problems related to the formation of sedimentary rocks and ores. Special attention is devoted to comparison of ancient sedimentary rock- and ore formation with present-day processes, as the idea of actualism has always constituted one of the bases of the scientific philosophy of lithologists. A major part of the journal is devoted to comparative analysis of sedimentary processes on continents and in oceans, as well as the genetic aspects of the formation of sedimentary and hydrothermal-sedimentary mineral resources. The journal was founded in 1963 by Academician N. M. Strakhov. It will be of interest to lithologists, petrographers, geochemists, mineralogists, ore geologists and metallogenists, as well as to other geologists, ecologists, researchers of experimental and analytical laboratories, and graduate students.

Lithology and Mineral Resources is abstracted or indexed in *Chemical Abstracts, Engineering Index,* and *Metal Abstracts Index*

Subscription Rates
1997 Volume 32 • 6 issues • ISSN 0024-4902
US$1495.00, outside the USA $1750.00

Subscription Office: Plenum/Consultants Bureau, 233 Spring Street, New York, NY 10013
Phone: (212) 620-8467; Fax: (212) 807-1047

Translated by **Institute of Marine Biology**

Published by **МАИК Наука/Interperiodica Publishing**
Distributed Worldwide by **Plenum/Consultants Bureau**

Russian Journal of Marine Biology

Editor-in-Chief
Vladimir I. Kasyanov
Corresponding Member of the Russian Academy of Sciences

SCOPE:

The *Russian Journal of Marine Biology* covers a wide range of research and some applied aspects of marine biology as a synthetic science related to various fields of study on marine biota and environment. It presents fundamental research on biological processes at molecular, cell, organism, and population levels in marine organisms. Consideration is given to marine objects as models in life sciences. The journal also publishes papers dedicated to events in Russian and international marine science and the history of biology. It is intended for scientists and specialists at research institutes, universities, and other educational establishments; and for those working at laboratories in fisheries and aquaculture.

Russian Journal of Marine Biology is abstracted or indexed in *Oceanic Abstracts, Biological Abstracts Geo Abstracts, Current Contents, International Abstracts of Biological Sciences, and Medicinal* and *Aromatic Plants Abstracts*

.Subscription Rates
1997 Volume 23• 6 issues • ISSN 1063-0740
US$835, outside the USA $975.00

Subscription Office: Plenum/Consultants Bureau, 233 Spring Street, New York, NY 10013
Phone: (212) 620-8467; Fax: (212) 807-1047

Subscribe to the journals from the Russian Academy of Sciences

Translated and Published by МАИК Наука/Interperiodica Publishing

Distributed Worldwide by INTERPERIODICA

Copy this form to mail or fax your order today

	TITLE	Volume	ISSN	ISSUES	RATE IN US DOLLARS US/CAN	RATE IN US DOLLARS INTERNATIONAL	YOUR ORDER
❑	**Agricultural Chemistry**	1	Pending	4	$459	$529	$ _____
❑	**Computational Mathematics and Mathematical Physics**	37	0965-5425	12	$1813	$2208	$ _____
❑	**Doklady Mathematics**	55/56	1064-5624	6	$1099	$1264	$ _____
❑	**Entomological Review**	77	0013-8738	9	$1689	$1942	$ _____
❑	**Eurasian Soil Science**	30	1064-2293	12	$1597	$1837	$ _____
❑	**Geochemistry International**	35	0016-7029	12	$1800	$2070	$ _____
❑	**Geology of Ore Deposits**	39	1075-7015	6	$769	$884	$ _____
❑	**Geotectonics**	31	0016-8521	6	$435	$472	$ _____
❑	**Herald of the Russian Academy of Sciences**	67	1019-3316	6	$949	$1205	$ _____
❑	**Izvestiya, Atmospheric and Oceanic Physics**	33	0001-4338	6	$605	$650	$ _____
❑	**Izvestiya, Physics of the Solid Earth**	33	1069-3513	12	$638	$702	$ _____
❑	**Journal of Communications Technology and Electronics**	42	1064-2269	12	$2091	$2405	$ _____
❑	**Journal of Computer and Systems Sciences International**	36	1064-2307	6	$1670	$1921	$ _____
❑	**Journal of Ichthyology**	37	0032-9452	9	$1451	$1669	$ _____
❑	**Laser Physics**	7	1054-660X	6	$874	$1055	$ _____
❑	**Oceanology**	37	0001-4370	6	$539	$581	$ _____
❑	**Paleontological Journal**	31	0031-0301	6	$1084	$1247	$ _____
❑	**Pattern Recognition & Image Analysis**	7	1054-6618	4	$549	$631	$ _____
❑	**Petrology**	5	0869-5911	6	$769	$884	$ _____
❑	**Polymer Science. Series A**	39	0965-545X	12	$2078	$2390	$ _____
❑	**Polymer Science. Series B**	39	Pending	6	$787	$905	$ _____
	Both Series A & B. $200 discount				$2665	$3095	$ _____
❑	**Proceedings of the Steklov Institute of Mathematics**	216-219	0081-5438	4	$809	$930	$ _____
❑	**Russian Journal of Inorganic Chemistry**	42	0036-0236	12	$2151	$2474	$ _____
❑	**Russian Journal of Physical Chemistry**	71	0036-0244	12	$2151	$2474	$ _____
❑	**Russian Journal of Zoology**	1	Pending	4	$459	$529	$ _____
❑	**Stratigraphy and Geological Correlation**	5	0869-5938	6	$769	$884	$ _____
❑	**Studies on Russian Economic Development**	8	1075-7007	6	$549	$631	$ _____
❑	**The Physics of Metals and Metallography**	83/84	0031-918X	12	$1876	$2157	$ _____
❑	**Thermophysics and Aeromechanics**	4	0869-8643	4	$499	$599	$ _____
❑	**Thermal Engineering**	44	0040-6015	12	$1198	$1378	$ _____
❑	**Transactions of the Russian Academy of Sciences/Earth Science Sections**	352-357A	0012-494X	9	$2287	$2630	$ _____

TOTAL _____

❶ Name _____
Institution _____
Address _____
_____
City _____ State _____
Zip/Postal Code _____ Country _____
Telephone (_____) _____

Delivery is not made until payment is received

To order by phone call **1 800 633-4931**
or (205) 995-1567 outside the US and Canada

❷ ❑ My payment for $_____ is enclosed.
OR
❑ Bill me. My library's purchase order number is _____

❸ Send this order and payment to:
INTERPERIODICA
P.O. Box 1831
Birmingham, AL 35201-1831
Or fax this order form to (205) 995-1588

Order now for immediate delivery. All journals will be published in 1997!

МАИК НАУКА/INTERPERIODICA PUBLISHING

is pleased to present to the international scientific community simultaneous Russian- and English-language publication of the journals of the Russian Academy of Sciences

МАИК НАУКА (NAUKA International Academic Publishing Company), in cooperation with the Russian Academy of Sciences, publishes the results of research in all fields of modern science performed by leading scientists and scientific institutions from Russia, the CIS, and other countries. Simultaneous English translation of the journals is provided by INTERPERIODICA Publishing, the translation division of МАИК НАУКА. Today, scientists around the world have direct access to the most significant Russian research at the time it is first published in Moscow – at the time it is most relevant to the worldwide scientific community. In addition to more timely publication, readers benefit from more precise translations of each journal, provided by a carefully chosen team of scientific translators with direct access to the authors and editors. English versions of the journals published by МАИК НАУКА/INTERPERIODICA PUBLISHING are distributed worldwide by INTERPERIODICA, Plenum/Consultants Bureau, and the American Institute of Physics.

МАИК НАУКА 1997 volumes include the following titles:

- *Agricultural Chemistry*
- *Computational Mathematics and Mathematical Physics*
- *Doklady Mathematics*
- *Entomological Review*
- *Eurasian Soil Science*
- *Geology of Ore Deposits*
- *Geochemistry International*
- *Geotectonics*
- *Herald of the Russian Academy of Sciences*
- *Izvestiya, Atmospheric and Oceanic Physics*
- *Izvestiya, Physics of the Solid Earth*
- *Journals of Communications Technology and Electronics*
- *Journal of Computer and Systems Sciences International*
- *Journal of Ichthyology*
- *Laser Physics*
- *Oceanology*
- *Paleontological Journal*
- *Pattern Recognition and Image Analysis*
- *Petrology*
- *Polymer Science, Series A*
- *Polymer Science, Series B*
- *Proceedings of the Steklov Institute of Mathematics*
- *Russian Journal of Inorganic Chemistry*
- *Russian Journal of Physical Chemistry*
- *Russian Journal of Zoology*
- *Stratigraphy and Geological Correlation*
- *Studies on Russian Economic Development*
- *The Physics of Metals and Metallography*
- *Thermophysics and Aeromechanics**
- *Thermal Engineering*
- *Transactions (Doklady) of the Russian Academy of Sciences/Earth Science Sections*

Please direct all inquiries about the above journals to: **INTERPERIODICA**, P.O. Box 1831, Birmingham, AL 35201-1831. For faster service call toll-free (800) 633-4931 or (205) 995-1567 (outside US and Canada). Fax: (205) 995-1588.
* *Thermophysics and Aeromechanics*: Only distributed by МАИК НАУКА/Interperiodica

- *Applied Biochemistry and Microbiology*
- *Biochemistry (Moscow)*
- *Biology Bulletin*
- *Colloid Journal*
- *Cosmic Research*
- *Doklady Biochemistry*
- *Doklady Biological Sciences*
- *Doklady Biophysics*
- *Doklady Botanical Sciences*
- *Doklady Chemical Technology*
- *Doklady Chemistry*
- *Doklady Physical Chemistry*
- *Glass Physics and Chemistry*
- *High Energy Chemistry*
- *High Temperature*
- *Human Physiology*
- *Inorganic Materials*
- *Instruments and Experimental Techniques*
- *Journal of Evolutionary Biochemistry and Physiology*
- *Journal of Analytical Chemistry*
- *Kinetics and Catalysis*
- *Lithology and Mineral Resources*
- *Microbiology*
- *Molecular Biology*
- *Programming and Computer Software*
- *Protection of Metals*
- *Radiochemistry*
- *Russian Journal of Applied Chemistry*
- *Russian Journal of Bioorganic Chemistry*
- *Russian Journal of Coordination Chemistry*
- *Russian Journal of Developmental Biology*
- *Russian Journal of Ecology*
- *Russian Journal of Electrochemistry*
- *Russian Journal of General Chemistry*
- *Russian Journal of Genetics*
- *Russian Journal of Marine Biology*
- *Russian Journal of Organic Chemistry*
- *Russian Journal of Plant Physiology*
- *Russian Microelectronics*
- *Solar System Research*
- *Theoretical Foundations of Chemical Engineering*
- *Water Resources*

Please direct all inquiries about the above journals to: **Plenum/Consultants Bureau**, 233 Spring Street, New York, NY 10013. Phone: (212) 620-8467. Fax: (212) 807-1047.

- *Acoustical Physics*
- *Astronomy Reports*
- *Astronomy Letters*
- *Crystallography Reports*
- *Optics and Spectroscopy**
- *Physics—Doklady*
- *Physics of Atomic Nuclei*
- *Plasma Physics Reports*

Please direct all inquiries about the above journals to: **American Institute of Physics**, Circulation and Fulfillment Services, 500 Sunnyside Boulevard, Woodbury, NY 11797-2999 USA. Tel. (516) 576-2270, (800) 344-6902. Fax: (516) 349-9704.
* *Optics and Spectroscopy*: Optical Society of America, 2010 Massachusetts Ave., NW, Washington, DC 20036-1023, Attn.: Publications Department. Tel. (202) 223-8130, (800) 582-0416. Fax: (202) 223-1096.

МАИК Наука/Interperiodica Publishing (International Academic Publishing Co. "Nauka")
Profsoyuznaya ul., 90, Moscow, 117864, Russia, Phone: 7 (095) 3361600; Fax: 7 (095) 336 0666, E-mail:compmg@maik.rssi.ru